DATA TRANSMITTAL REPORT FOR THE YELLOWSTONE NATIONAL PARK WINTER USE AIR QUALITY STUDY DECEMBER 16, 2003 – MARCH 15, 2004

Prepared for

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1.0 INTRODUCTION

Air Resource Specialists, Inc. (ARS) was contracted by the National Park Service (NPS) to conduct an air quality monitoring study in Yellowstone National Park to help assess the impact of human-caused pollutants during periods of winter activity. In the winter months, Yellowstone National Park opens roads to over snow vehicles (snowmobiles and snow coaches) as soon as adequate snow accumulations and safe driving conditions allow.

The monitoring program began December 16, 2003, and ran through March 15, 2004. The monitoring effort included meteorological, gaseous, particulate, optical and photographic monitoring near Old Faithful geyser. The meteorological, gaseous, particulate and optical variables were monitored continuously. A time-lapse video system and digital camera captured images of the monitoring shelter and warming hut. Gaseous, particulate and meteorological data collected by the State of Montana at the West Entrance to the park were also included in the study.

This data report presents all data collected during the study period, December 16, 2003, through March 15, 2004. The report is organized into the following major sections:

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2.0 SITE LOCATIONS AND CONFIGURATIONS

Monitoring was conducted by ARS in the Old Faithful area of Yellowstone National Park. Monitoring was conducted by the State of Montana at the West Entrance of the park. Table 2-1 summarizes the instrumentation type and data collection parameters for each site. A map detailing the locations of the monitoring sites is presented as Figure 2-1.

2.1 OLD FAITHFUL MONITORING SITE

The Old Faithful monitoring shelter was located to the east of the main parking lot for the Snow Lodge and south of the Old Faithful geyser. Instrumentation at the site included a nephelometer for collection of particle scattering, Beta Attenuation Monitor (BAM) for collection of $PM_{2.5}$, Carbon Monoxide (CO) analyzer, wind speed/wind direction sensor, ambient temperature and relative humidity sensor. A time-lapse video camera and a digital camera were installed on the Park Rangers' station and overlooked the main vehicle parking lot. Figure 2-2 presents a photograph of the Old Faithful monitoring site.

The Old Faithful shelter was located within 50 feet of one of the warming huts in the Old Faithful visitor area. The warming huts were warmed by wood-burning stoves. At times, the smoke from the stack could be seen blowing directly at the air quality shelter. Figure 2-3 presents a photograph of the warming hut and the Old Faithful shelter.

This shelter was also located in close proximity to the Old Faithful geyser. Geysers can emit several types of gases. The most abundant gas is carbon dioxide, but geysers can also emit oxygen, carbon monoxide, hydrogen methane, nitrogen, argon and hydrogen sulfide. Old Faithful is the most regular geyser in the basin area and erupts approximately every 60-90 minutes. Figure 2-4 presents a map of the Old Faithful area.

Table 2-1
Yellowstone National Park
Winter Use Air Quality Monitoring Study Instrumentation
December 16, 2003 - March 15, 2004

Site Name	Sampler	Sampler Type	Sampler Model No.	Averaging Period	Sample Frequency
Old Faithful	Particulate	BAM $PM_{2.5}$ (ThermoAndersen)	FH 62 C14	1-hour	Continuous
	Gaseous	CO Analyzer (Thermo Environmental)	TEI 48C	1-hour	Continuous
	Meteorological	Wind Speed and Wind Direction (R.M. Young)	05305	1-hour	Continuous
	Meteorological	Primary Ambient Temperature and Relative Humidity (Rotronics)	MP101A-C4	1-hour	Continuous
	Meteorological	Secondary Ambient Temperature and Relative Humidity (Rotronics)	MP101A-C4	5-min	Continuous
	Photographic	Digital Camera (Kodak)	HRDC-1	--	Every 15 minutes
	Time lapse video	Time Lapse Recorder (Panasonic)	SVHS	4-seconds	continuous
	Optical	Nephelometer (Optec)	NGN-2	2-min (every 5-min)	Continuous
West Entrance	Particulate	BAM $PM_{2.5}$ (Met One)	BAM 1020	1-hour	Continuous
	Gaseous	CO Analyzer (Advanced Pollution Instruments)	API 300	1-hour	Continuous
	Meteorological	Ambient Temperature, Wind Speed, and Wind direction (Climatronics)	--	1-hour	Continuous

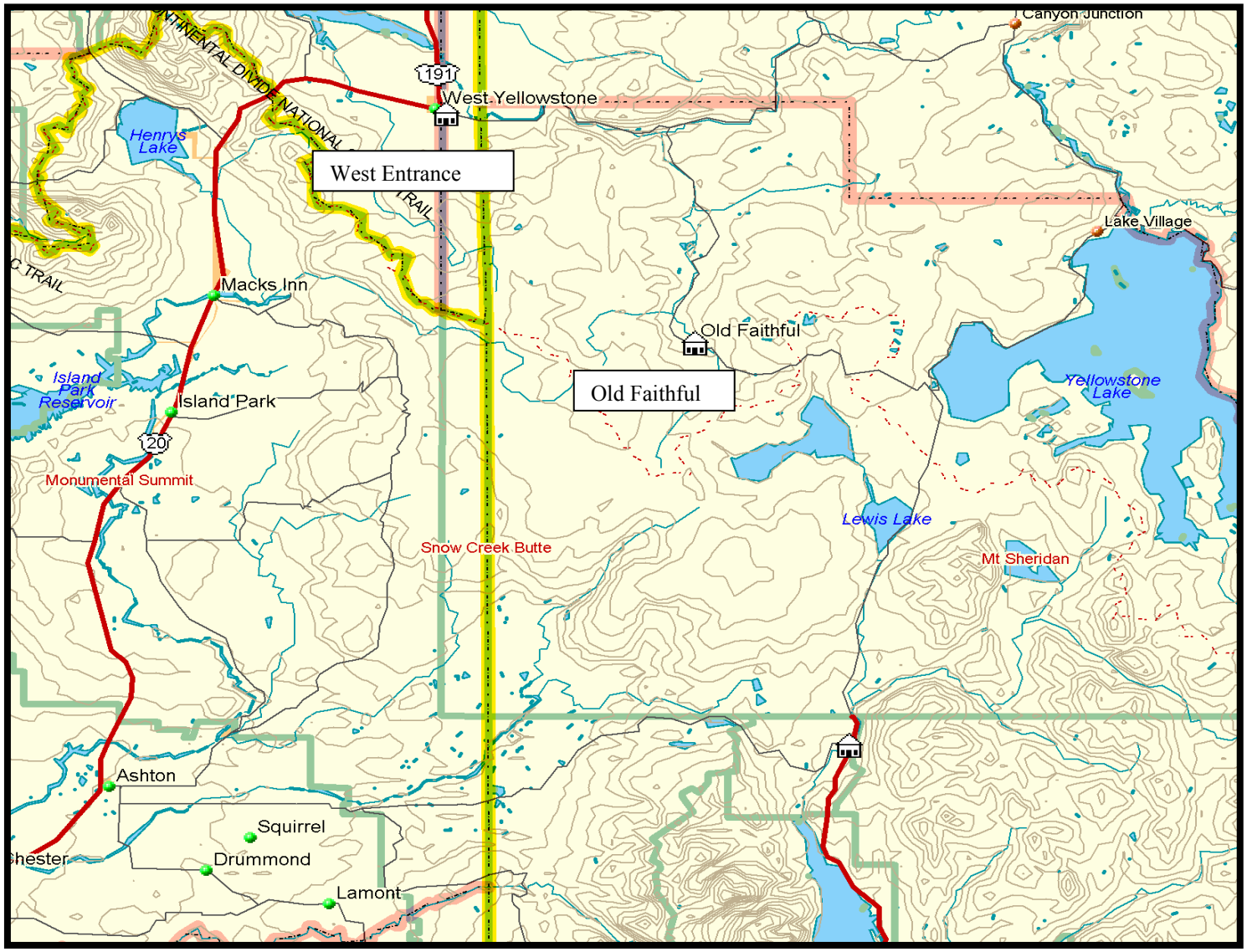


Figure 2-1. Monitoring Site Locations.

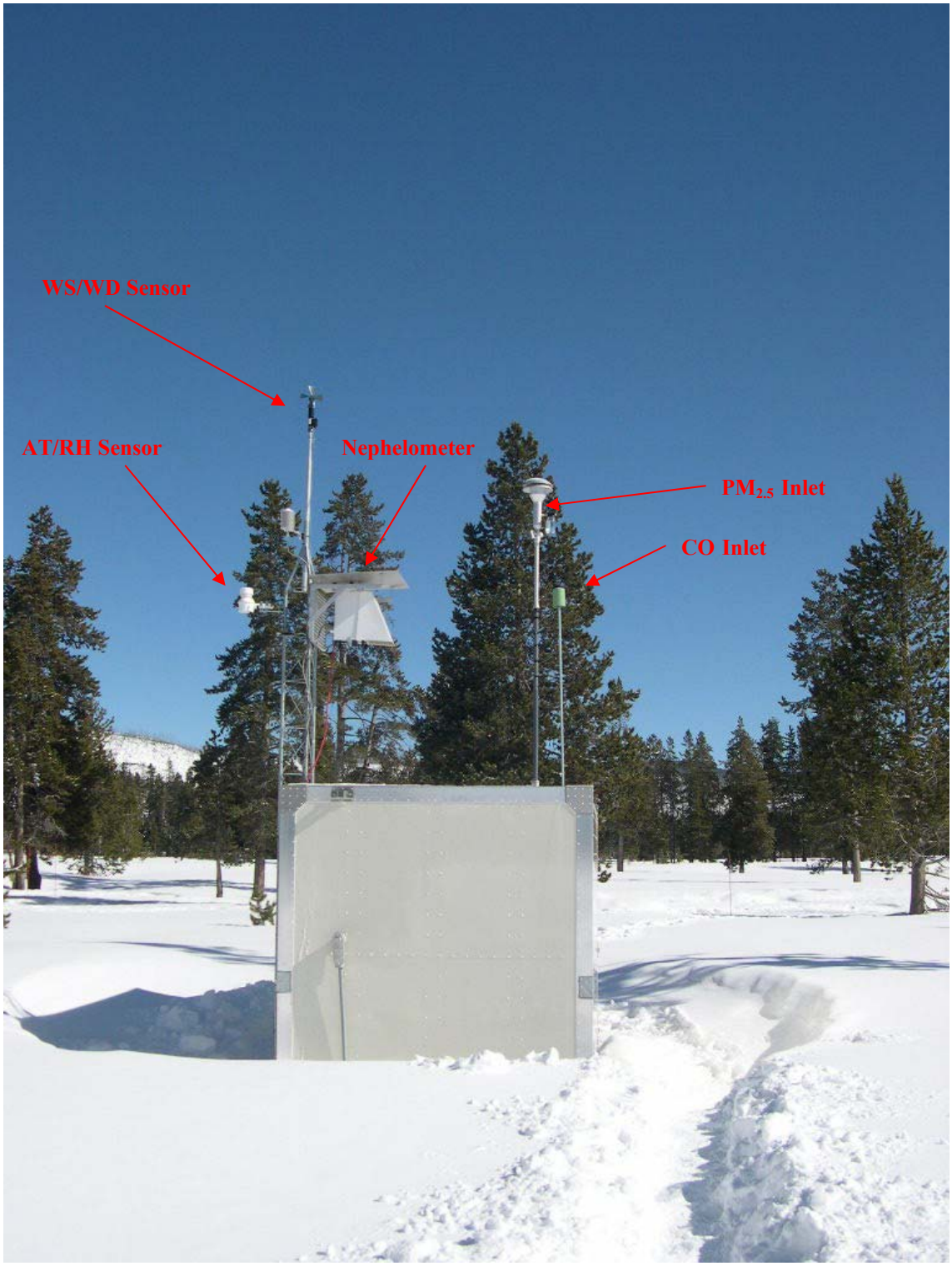


Figure 2-2. Monitoring Shelter at the Old Faithful Site.

Figure 2-3. Old Faithful Monitoring Site Shelter and Warming Hut.

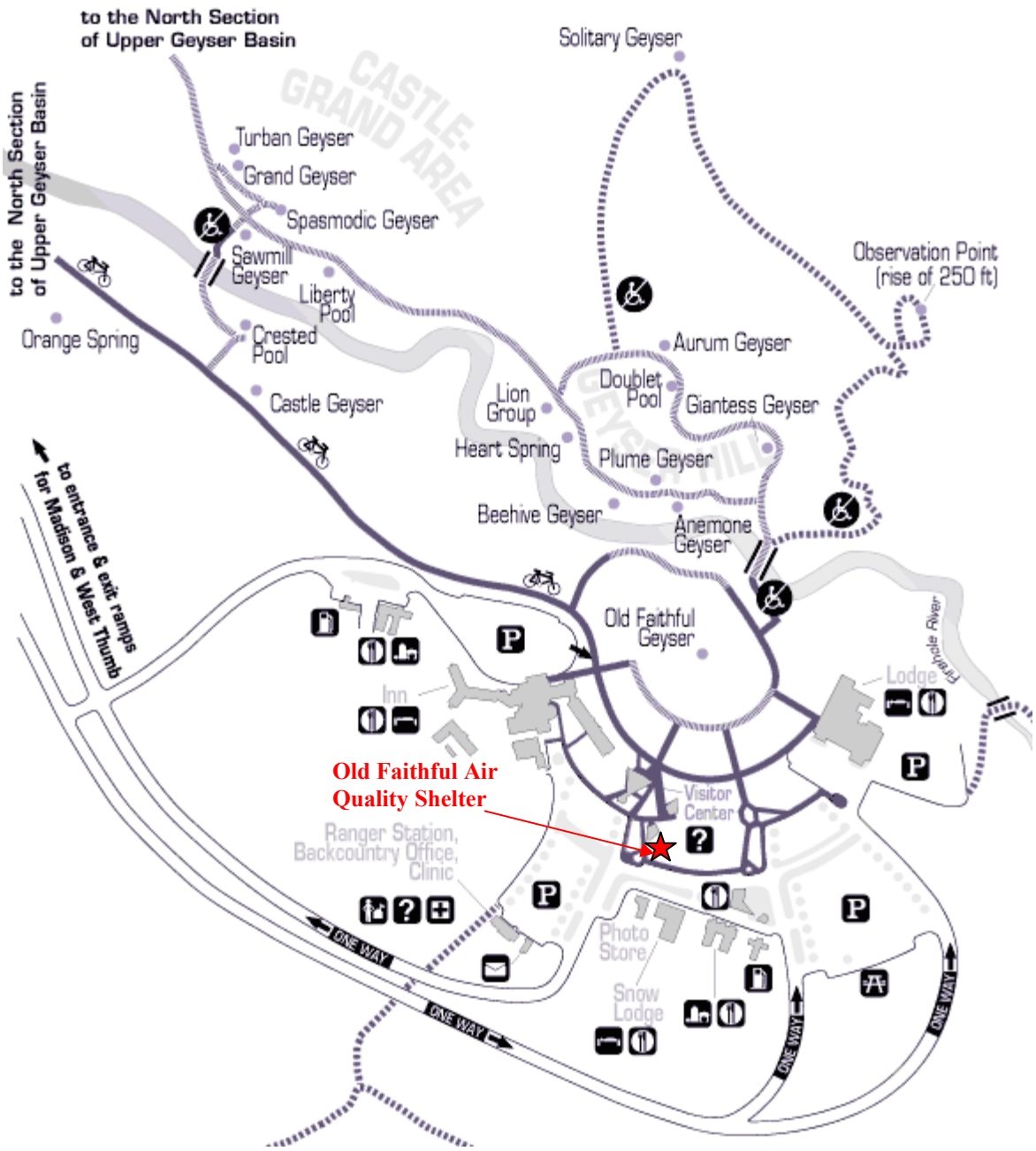


Figure 2-4. Old Faithful Area Map.

3.0 DATA COLLECTION, VALIDATION, AND QUALITY ASSURANCE

This section describes the instrumentation, data acquisition, validation, and quality assurance of particulate, gaseous, optical, meteorological and photographic monitoring data collected by ARS during the study .

3.1 SUMMARY OF AIR QUALITY AND METEOROLOGICAL MONITORING

At the Old Faithful site continuous carbon monoxide and $PM_{2.5}$ analyzers were operated during the study to help assess the impact of human-caused pollutants during periods of winter activity. Meteorological sensors were operated during the study to better characterize the overall meteorology of the region. All continuous gaseous, particulate and meteorological data were collected with the site ESC8816 data logger. The data logger sampled the measurement channels at a frequency of once per second and averages were calculated and reported at 1-hr intervals. The data logger was connected to a telephone modem, allowing remote access of the data. The data were downloaded nightly. This section describes the collection, validation, and quality assurance of data collected by ARS at the Old Faithful site.

The State of Montana collected carbon monoxide, $PM_{2.5}$, and meteorological data at the West Entrance of the park. This data was retrieved from EPA AIRS and directly from the State of Montana. All data collection, validation, and quality assurance steps were performed by the State of Montana.

3.1.1 Air Quality and Meteorological Monitoring System

The air quality and meteorological monitoring system at Old Faithful consisted of the following instruments:

- Thermo Environmental (TEI) 48C CO analyzer
- ThermoAndersen Model FH 62 C14 Beta Attenuation Monitor (BAM) with a $PM_{2.5}$ size cut.
- Rotronics MP-101A Air Temperature/Relative Humidity (AT/RH) sensor
- R.M. Young Model #05305 Wind Sensor

3.1.2 Air Quality and Meteorological Data Collection and Validation

Gaseous, particulate and meteorological data collection and validation steps included:

- Raw hourly carbon monoxide, PM2.5, and meteorological data collected nightly via modem and uploaded to the Air Quality Database (AQDB).
- Raw and daily calibration (zero and span) data were plotted and reviewed weekly to identify operational problems and initiate corrective procedures as soon as possible.

- Information from communications with the operators was used to identify inconsistencies and errors in the data.
- Recording and reviewing comments on raw data stackplots, and entering validation codes and adjusting values in the AQDB as needed.
- Reviewing validated stackplots, resolving all inconsistencies and labeling the data as final validated.

3.1.3 Air Quality and Meteorological Sensor Uncertainty

The sensors were calibrated immediately after installation, during maintenance activities, and at project takedown. Calibration and maintenance results are presented in Appendix A.

The detection limit for the ThermoAnderson Beta Attenuation Monitor (BAM) is approximately 6 ug/m^3 for 1-hr averages.

3.2 SUMMARY OF OPTICAL MONITORING

An ambient nephelometer collected continuous measurements of the ambient atmospheric particle scattering coefficient (bsp) at the Old Faithful site. An ambient temperature/relative humidity (AT/RH) sensor was collocated with the nephelometer for data validation and interpretation purposes. Data was collected with a datalogger and downloaded via telephone modem daily. The data were then validated according to IMPROVE protocol. Standard Operating Procedures (SOPs) and Technical Instructions (TIs) that fully describe the applied acquisition and reduction procedures include:

- SOP 4300 Collection of Optical Monitoring Data (IMPROVE Protocol)
- TI 4300-4002 Nephelometer Data Collection via Telephone Modem (IMPROVE Protocol)
- TI 4300-4006 Nephelometer Data Collection via Campbell Scientific Data Storage Module (IMPROVE Protocol)
- TI 4400-5010 Nephelometer Data Reduction and Validation (IMPROVE Protocol)

3.2.1 Nephelometer Monitoring System

The nephelometer system was configured with the following instrumentation:

- Optec NGN-2 Ambient Nephelometer
- Rotronic MP-101A AT/RH sensor with motor aspirated shield
- Serial/Analog Data Acquisition System (Campbell Scientific 21X datalogger)
- Manual span gas system (SUVA 134a span gas, gas regulator, and supply hoses)
- Nephelometer hood
- Mounting tower and hardware

Sensor and sampling specifications are summarized in Table 3-1.

Table 3-1
NGN-2 Ambient Nephelometer and AT/RH Sensor
Station Sensor and Sampling Specifications

Parameter	Sensor	Units	Sample Frequency	Notes
Nephelometer Raw readings	Optec NGN-2 Nephelometer	mVDC and Counts	2-minute average samples every 5 minutes	Optec NGN-2 Serial Output Logged
Nephelometer clean air calibration readings	Optec NGN-2 Nephelometer	mVDC and Counts	10-minute average at approximately 6-hour intervals	Start time drifts as controlled by Optec NGN-2 software
Nephelometer span calibrations (SUVA 134a)	Optec NGN-2 Nephelometer	mVDC and Counts	10-minute average performed manually at approximately 7-14 day intervals	Operator initiated during site visits
Nephelometer operating mode code	Optec NGN-2 Nephelometer	Unit less	1 code per nephelometer raw reading	Optec NGN-2 Serial Output Logged
Chamber temperature	Solid State Sensor	C	Concurrent with nephelometer reading	Available on serial data stream only
Ambient temperature	Rotronic MP-101A solid-state AT/RH	C (-30 to +50C)	Concurrent with nephelometer reading (5-minute averages of 10-second samples)	Sensor in forced air radiation shield
Ambient relative humidity	Rotronic MP-101A solid-state AT/RH	%RH (0 to 100%)	Concurrent with nephelometer reading (5-minute averages of 10-second samples)	Sensor in forced air radiation shield

3.2.2 Nephelometer Data Collection and Validation

Raw nephelometer and associated AT and RH data were collected by an on-site Campbell 21X datalogger. The nephelometer was operated on Mountain Standard Time in a 5-minute cycled mode, as described in Table 3-1. Clean air calibrations were automatically performed at approximately 6-hour intervals. Manual clean air and span gas calibrations were performed at approximately 7-14 day intervals.

Raw data were retrieved from the site and reviewed daily. Diagnostic data, calibrations, and information from log sheets were used to identify inconsistencies and errors. Corrective action was taken as appropriate.

Nephelometer measurements can be greatly influenced during periods of fog, heavy rain, high relative humidity, blowing snow, and other extreme meteorological conditions. Under these conditions, nephelometer readings will no longer correspond to the optical properties of particulates in the atmosphere. Periods of potential meteorological interference were identified using the following filters:

- Maximum: hourly bsp data exceeding 5000Mm-1 was coded as weather-affected.
- Relative Humidity: hourly bsp data when the relative humidity exceeded 90% was coded as weather-affected.

Standard IMPROVE protocol for nephelometer data validation allows for other tests based on the rate of change of measured scattering from one hour to the next, but it was decided not to use those tests on data collected at Old Faithful due to the high variability of local influences in the area. Time-lapse video and digital images of the Old Faithful parking lot and building complex were used to determine periods of fog which affected the nephelometer. Nephelometer data during periods of visible fog, regardless of the measured relative humidity, were invalidated.

3.2.3 Nephelometer and AT/RH Sensor Uncertainty

The measurement uncertainty of the Optec NGN-2 ambient nephelometer is calculated from the distribution of calibration slopes determined during manual span/zero calibrations. The reported uncertainty is the 95% confidence limit of a two-tailed t-distribution. The overall uncertainty for the nephelometer for the study period was 17%.

The AT/RH sensor collocated with the nephelometer was calibrated prior to installation and shown to perform within the manufacturer's specifications during the reporting period.

3.3 SUMMARY OF PHOTOGRAPHIC MONITORING

Routine time-lapse video monitoring was conducted at the Old Faithful site to document weather conditions, type and intensity of activity, and the presence of haze or exhaust. Routine

photographic monitoring consisted of digital photographs taken every 15 minutes of the same scene.

The area used for parking snowmobiles during the study was across the parking lot from the time-lapse video and digital cameras. Due to the distance between cameras and vehicles and the snow piles created by the snow ploughs, it was not possible to consistently document the magnitude of snowmobiles and snow coaches at the Old Faithful parking area, or related exhaust emissions. Video and still images were, however, used to support validation of nephelometer data. The video, in particular, was useful for identifying short-term (<1hour) weather episodes.

4.0 DATA SUMMARIES

This section presents a summary of all of the data collected by ARS and the State of Montana during the period, December 16, 2003, through March 15, 2004. Vehicle count data obtained from the National Park Service is also presented. Tabular data is available in Appendix B.

4.1 DATA COLLECTION AND VALIDATION STATISTICS

Table 4-1 and 4-2 list the data collection statistics for the study period for the Old Faithful and West Entrance sites. The data recovery for meteorological parameters during the period exceeded the project goals of 90%. Particulate and carbon monoxide data recovery exceeded the study goal of 80%.

4.1.1 Old Faithful

The CO analyzer at the Old Faithful site experienced a significant amount of zero drift over the study period. The raw ambient data was zero adjusted when the daily zero calibration check was greater than 1% of the instruments full scale value (0.2 ppm).

4.1.2 West Entrance

Data for the West Entrance site is collected by the State of Montana. ARS retrieved the gaseous and particulate data from EPA AIRS and the meteorological data from the state. No significant data loss occurred at this site during the study.

4.2 DATA TIME SERIES

Time series plots for both sites showing gaseous, particulate, meteorological, and optical parameters can be found in Figures 4-1 through 4-8.

Table 4-1

Data Collection Statistics
Yellowstone National Park – Old Faithful
Winter Use Air Quality Monitoring Study

12/16/2003 – 03/15/2004

Parameter	Interval	Par Code	Data Recovery			Valid Data	
			No. Possible	No. Collected	% Collected	No. Valid	% Valid
Carbon Monoxide	hourly	CO	2184	2119	97.0	2119	97.0
PM2.5 BAM	hourly	PM25B	2184	2179	99.8	2179	99.8
Relative Humidity	hourly	RH	2184	2181	99.9	2181	99.9
Standard Deviation for Wind Direction	hourly	SDWD	2184	2179	99.8	2179	99.8
Station Temperature	hourly	STP	2184	2179	99.8	2179	99.8
Scalar Wind Speed	hourly	SWS	2184	2181	99.9	2181	99.9
Ambient Temperature (aspirated)	hourly	TMP	2184	2181	99.9	2181	99.9
Unit Vector Wind Direction	hourly	VWD	2184	2179	99.8	2179	99.8
Particle Scattering	hourly	BSPF	2184	2184	100.0	2137	97.8

Notes: The percent valid is calculated against the number possible.
Automatic zeros and spans are performed daily on most ambient gas analyzers, therefore, no ambient data can be Collected during this time. As a result the maximum percent valid for ambient gas data typically cannot be greater than 95.8

Table 4-2

Data Collection Statistics
Yellowstone National Park – West Entrance
Winter Use Air Quality Monitoring Study

12/16/2003 – 03/15/2004

Parameter	Interval	Par Code	Data Recovery			Valid Data	
			No. Possible	No. Collected	% Collected	No. Valid	% Valid
Carbon Monoxide	hourly	CO	2183	2162	99.0	2119	94.9
PM2.5 BAM	hourly	PM25B	2184	2183	99.9	2182	99.9
Scalar Wind Speed	hourly	SWS	2184	2184	100.0	2181	100.0
Ambient Temperature (aspirated)	hourly	TMP	2184	2184	100.0	2181	100.0
Unit Vector Wind Direction	hourly	VWD	2184	2184	100.0	2179	100.0

Notes: The percent valid is calculated against the number possible.
Automatic zeros and spans are performed daily on most ambient gas analyzers, therefore, no ambient data can be Collected during this time. As a result the maximum percent valid for ambient gas data typically cannot be greater than 95.8

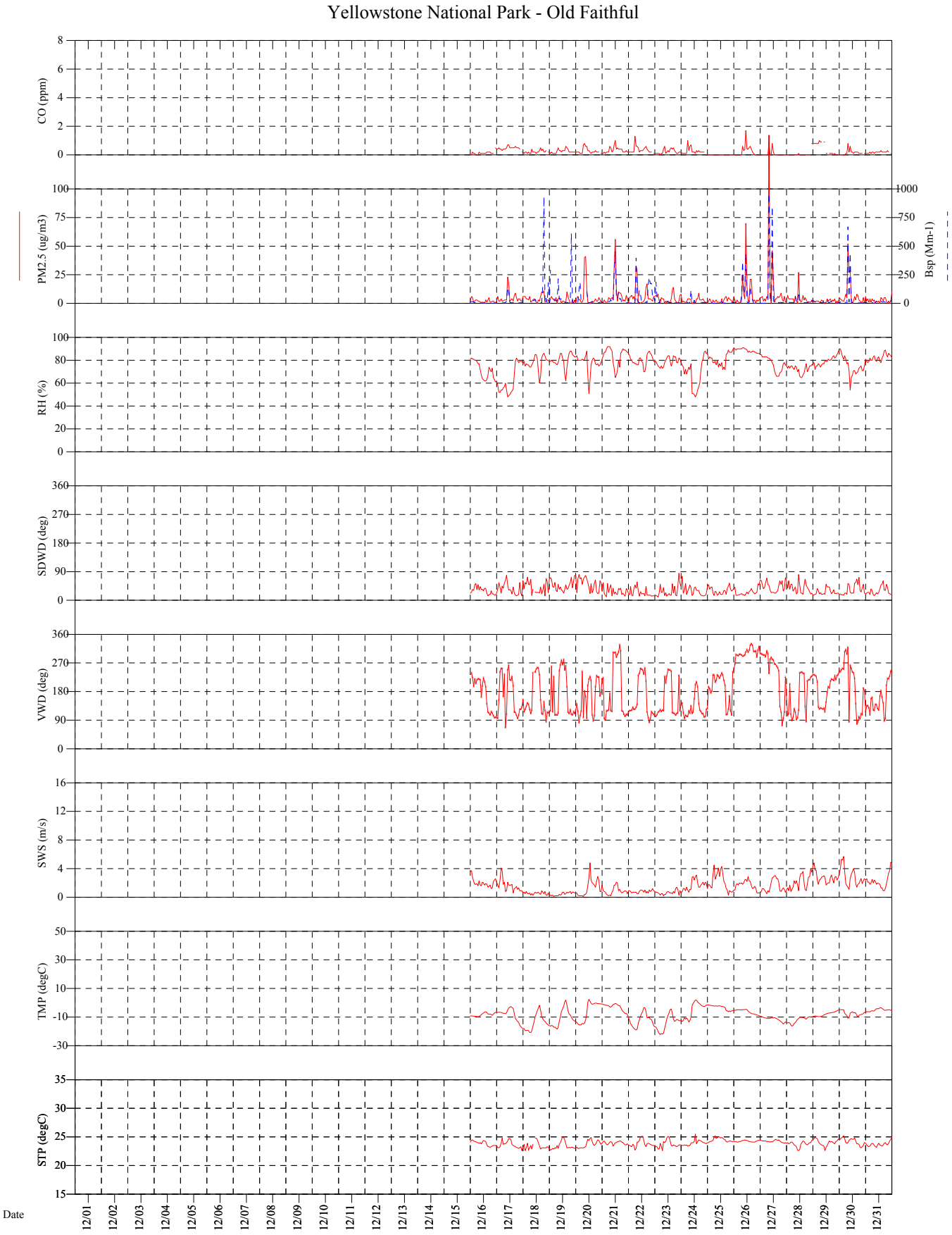


Figure 4-1. Timeline Plots for Old Faithful, December 2003

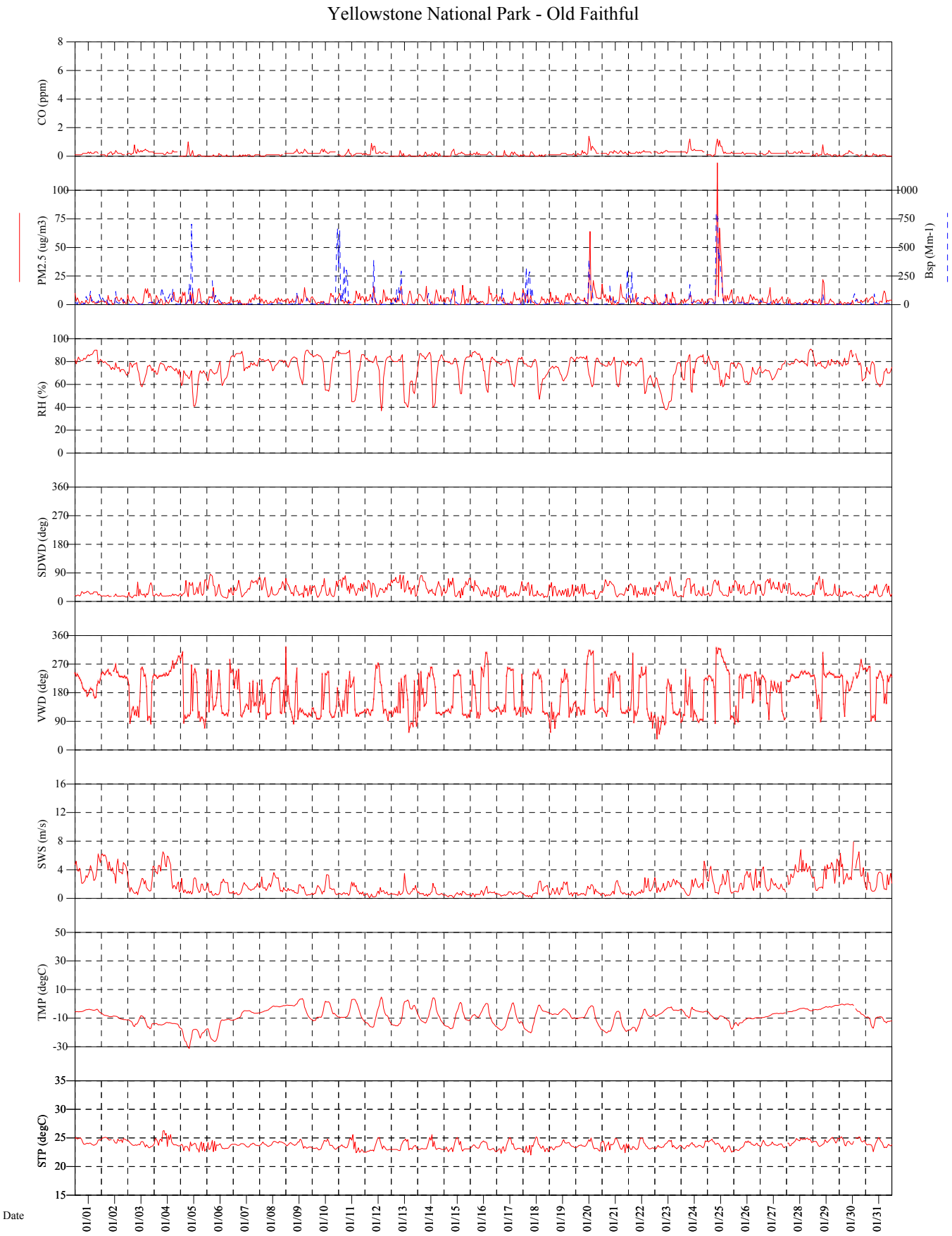


Figure 4-2. Timeline Plots for Old Faithful, January 2004

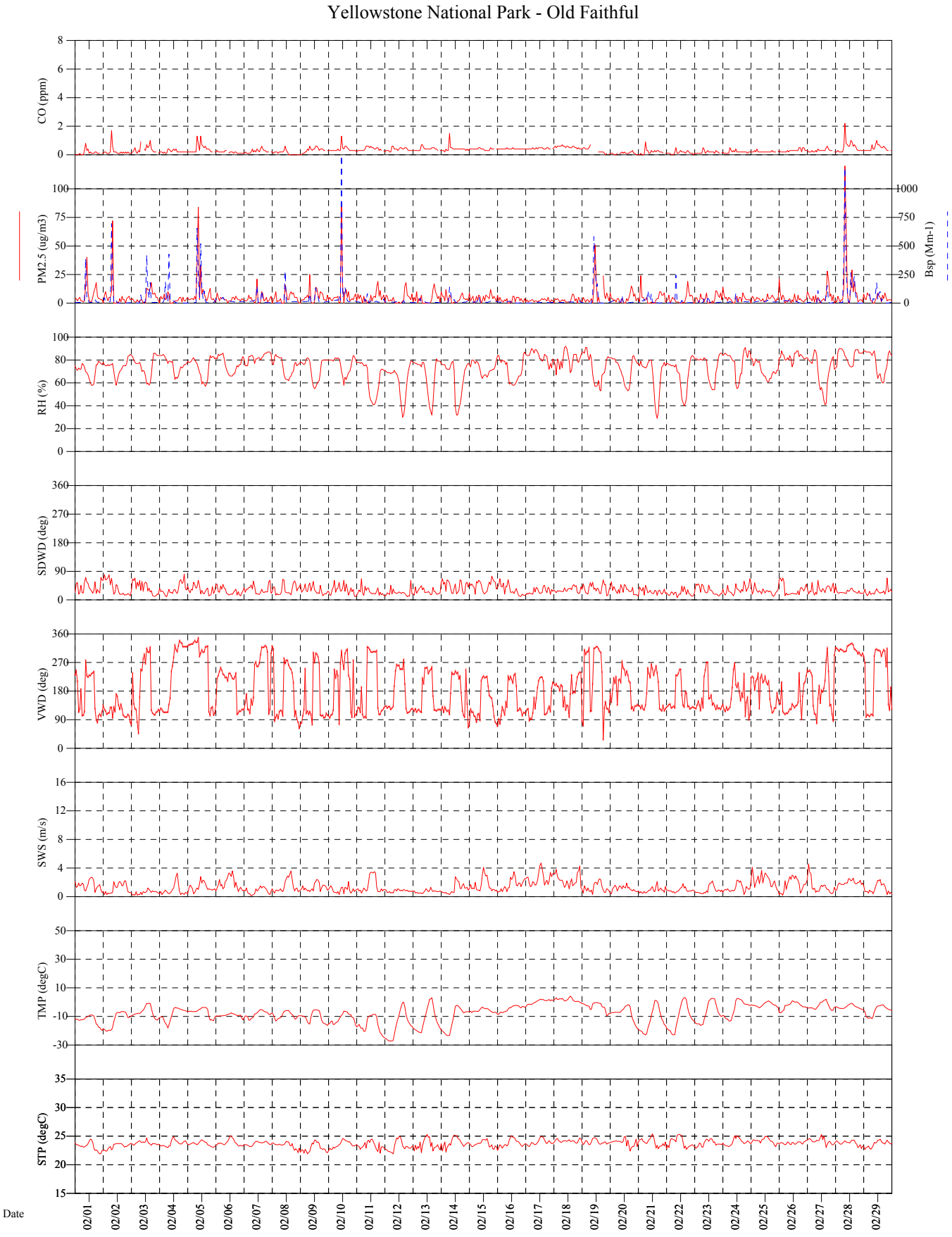
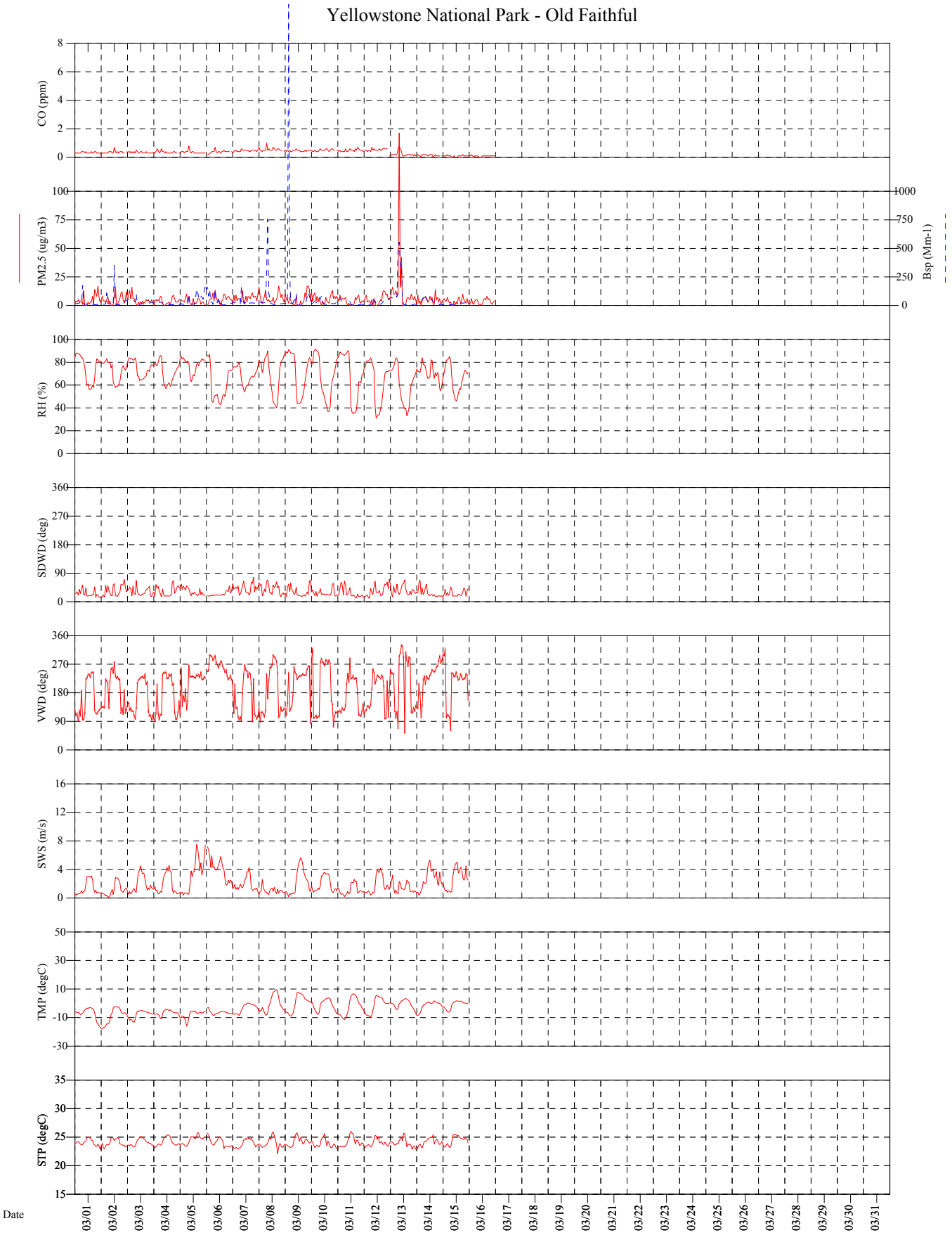


Figure 4-3. Timeline Plots for Old Faithful, February 2004

FINAL VALIDATED DATA



FINAL VALIDATED DATA

Figure 4-4. Timeline Plots for Old Faithful, March 2004

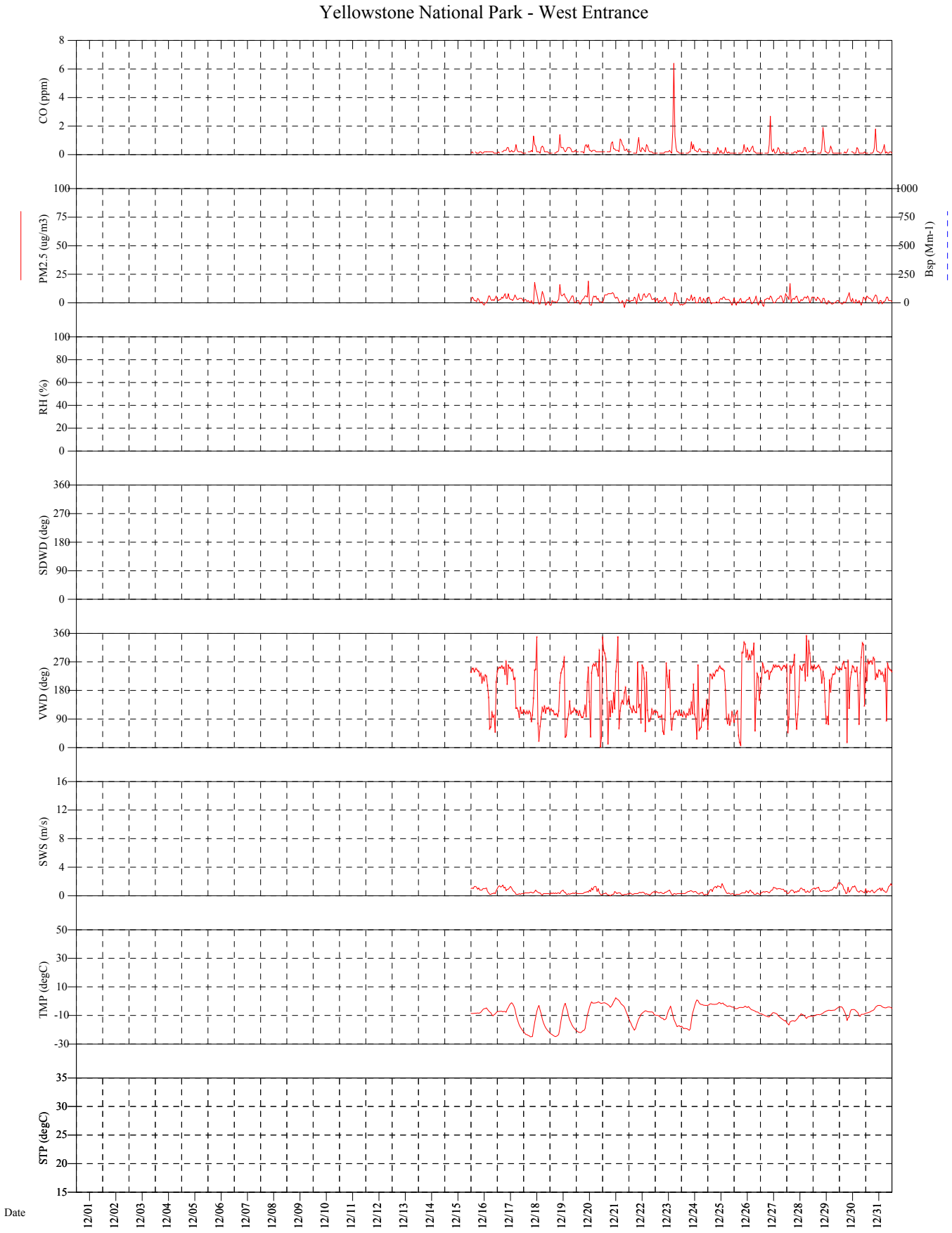
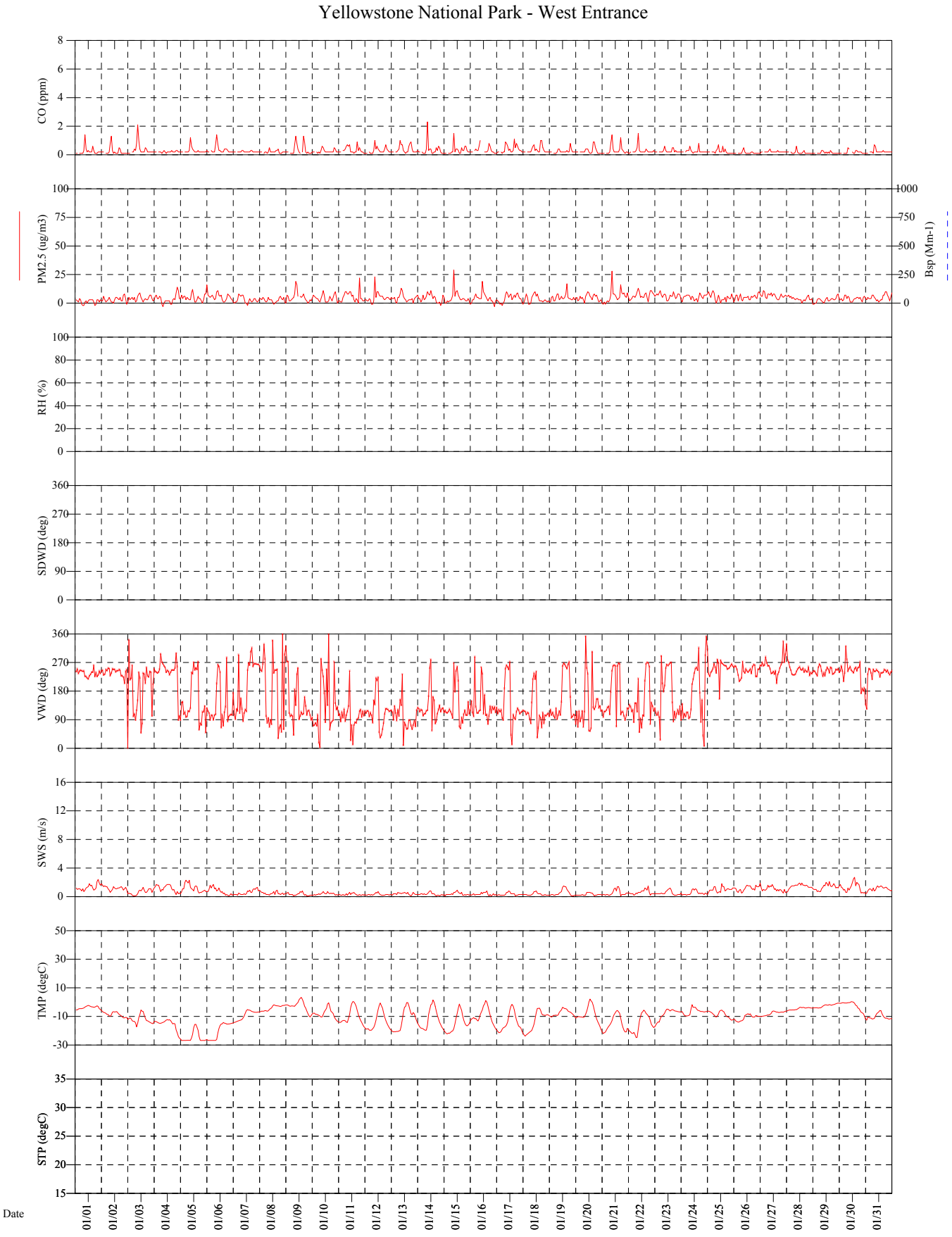


Figure 4-5. Timeline Plots for West Entrance, December 2003



FINAL VALIDATED DATA

Figure 4-6. Timeline Plots for West Entrance, January 2004

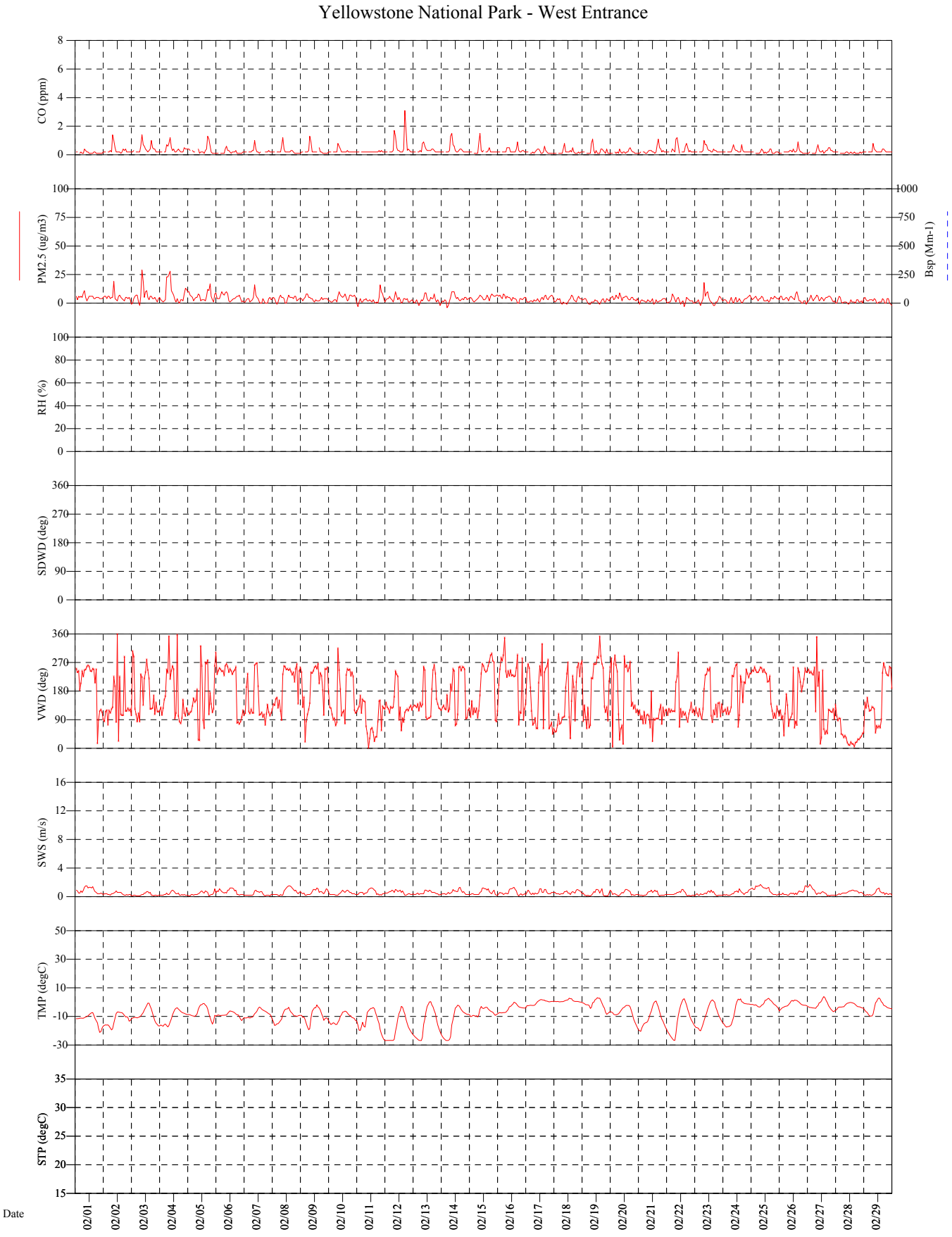


Figure 4-7. Timeline Plots for West Entrance, February 2004

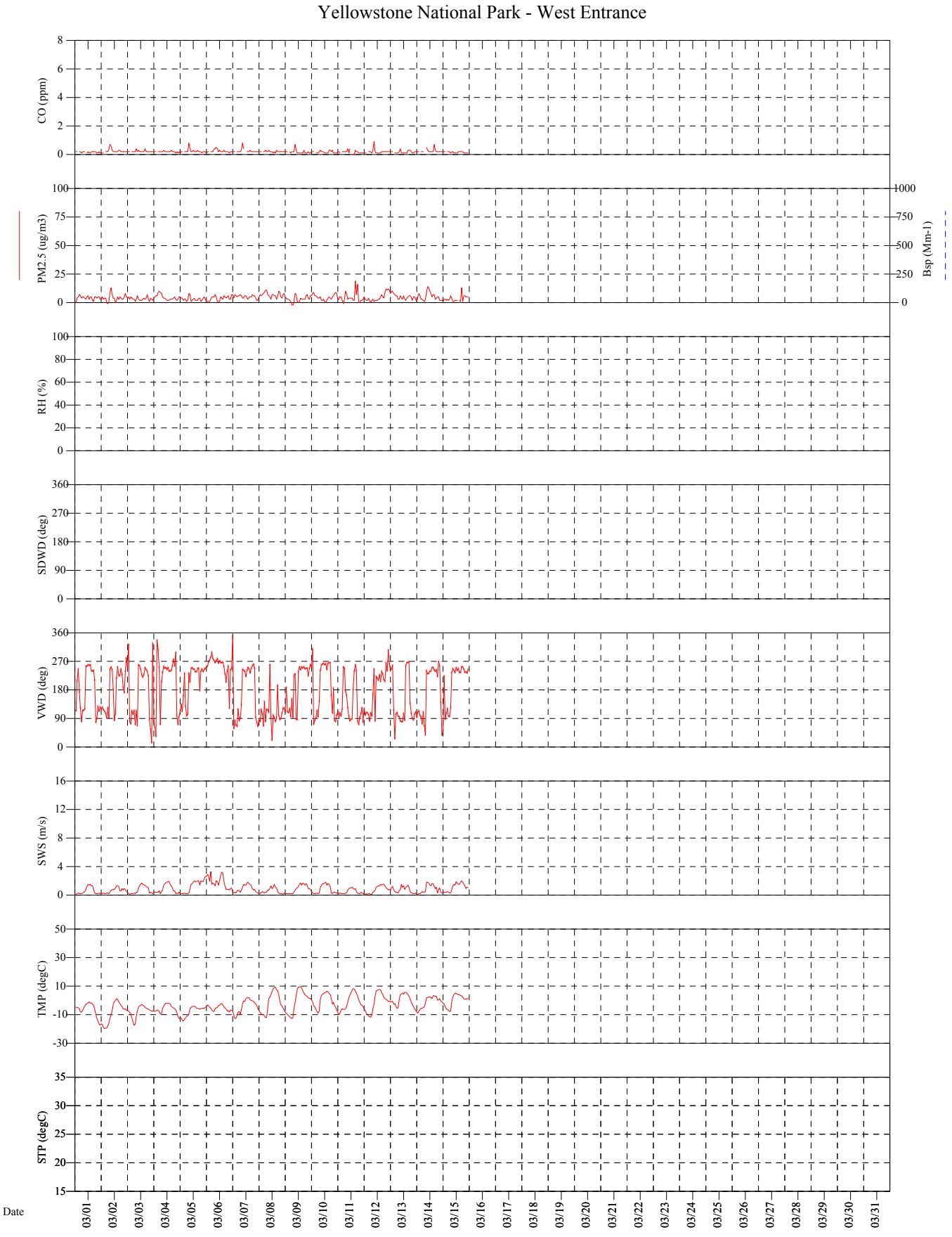


Figure 4-8. Timeline Plots for West Entrance, March 2004

4.3 METEOROLOGICAL DATA

Table 4-3 and 4-4 present meteorological data summary statistics for the study period for the Old Faithful and West Entrance sites. Figures 4-9 and 4-10 present wind roses for the study period for both sites. Winds at the Old Faithful site were mixed with directions predominantly out of the west-southwest to southwest and east-southeast to southeast equally. The highest winds speeds were seen when the winds were coming from the southwest. Winds at the West Entrance site were light and predominantly out of the west-southwest. This site experienced calm conditions nearly 44% of the time.

Table 4-3

Summary of Selected Meteorological Data

Yellowstone National Park - Old Faithful

Final Validation

12/16/2003 - 03/15/2004

Parameter	Value	Units	Number	Std Dev
SCALAR WIND SPEED				
Average	1.6	m/s	2181	1.2
Maximum	7.9	m/s		
Percent calm = 6.60				
AMBIENT TEMPERATURE				
Average	-7.6	degC	2181	6.1
Maximum	9.6	degC		
Minimum	-31.2	degC		
RELATIVE HUMIDITY				
Average	74	percent	2181	12
Maximum	92	percent		
Minimum	29	percent		
PRECIPITATION (Rainfall or Snow melt)				
Average non-zero rate	NA			
Maximum non-zero rate				
Minimum non-zero rate				
Accumulated during period				
SOLAR RADIATION				
Average Daily Total	NA			
Maximum Daily Total				
Minimum Daily Total				

Note: Calms are included in the average scalar wind speed and are defined as winds less than 0.5 m/s (1.0 mph).

Solar radiation terms are based on the calculation of the total amount of solar energy incident on a unit area during each day. The maximum and minimum daily totals are selected from the list of daily totals. The totals for all days are then added and divided by the number of days to yield the average daily total. Only days with 24 valid values are included in these statistics.

NA indicates instrument not available.

Table 4-4

Summary of Selected Meteorological Data

West Yellowstone Park Entrance

Final Validation

12/16/2003 - 03/15/2004

Parameter	Value	Units	Number	Std Dev
SCALAR WIND SPEED				
Average	0.7	m/s	2184	0.5
Maximum	3.3	m/s		
Percent calm = 45.05				
AMBIENT TEMPERATURE				
Average	-8.2	degC	2184	7.0
Maximum	9.7	degC		
Minimum	-26.9	degC		
RELATIVE HUMIDITY				
Average	NA			
Maximum				
Minimum				
PRECIPITATION (Rainfall or Snow melt)				
Average non-zero rate	NA			
Maximum non-zero rate				
Minimum non-zero rate				
Accumulated during period				
SOLAR RADIATION				
Average Daily Total	NA			
Maximum Daily Total				
Minimum Daily Total				

Note: Calms are included in the average scalar wind speed and are defined as winds less than 0.5 m/s (1.0 mph).

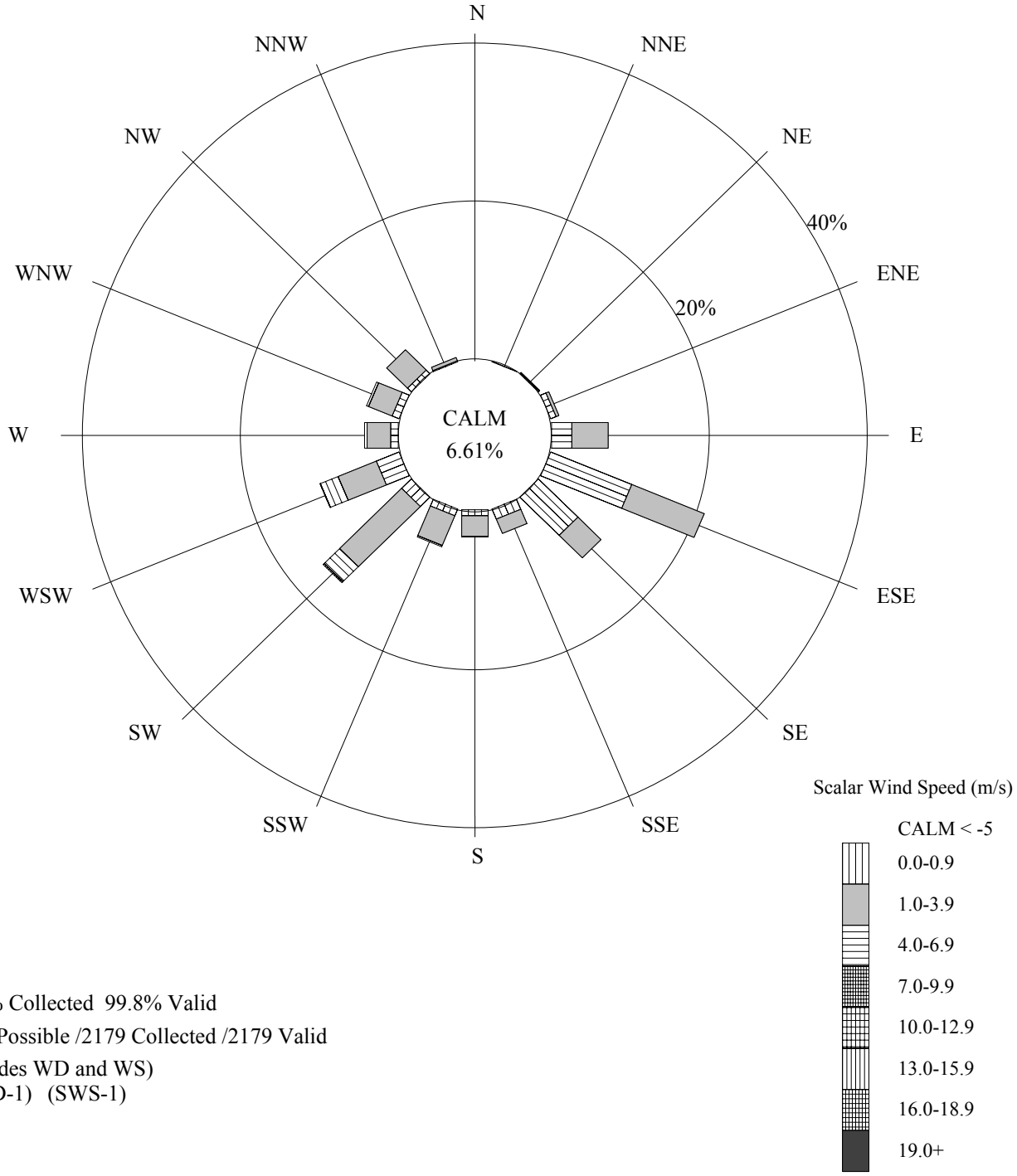
Solar radiation terms are based on the calculation of the total amount of solar energy incident on a unit area during each day. The maximum and minimum daily totals are selected from the list of daily totals. The totals for all days are then added and divided by the number of days to yield the average daily total. Only days with 24 valid values are included in these statistics.

NA indicates instrument not available.

Yellowstone National Park
Old Faithful

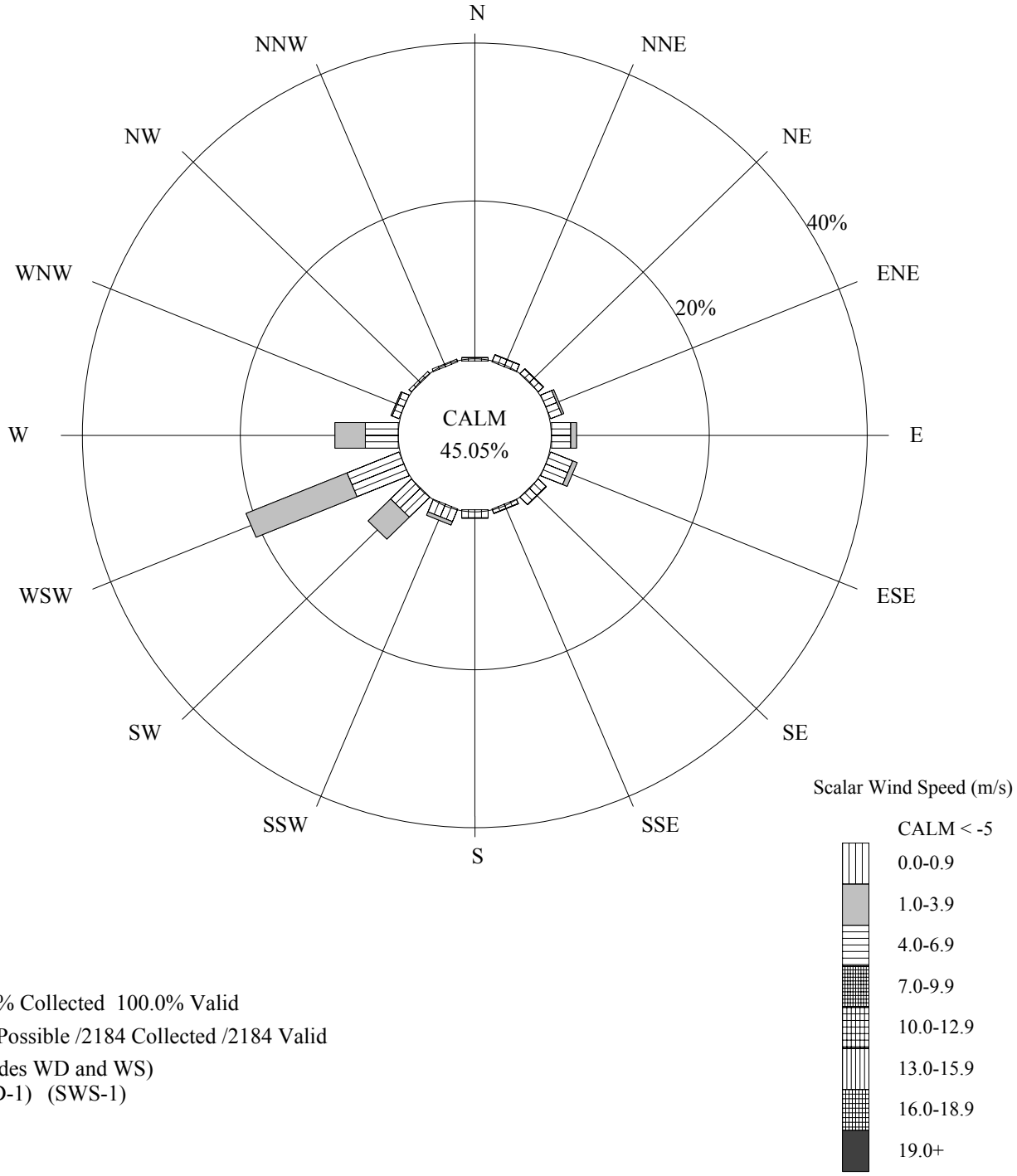
Wind Rose

12/16/2003 - 03/15/2004



99.8% Collected 99.8% Valid
2184 Possible /2179 Collected /2179 Valid
(includes WD and WS)
(VWD-1) (SWS-1)

Figure 4-9. Wind Rose for Old Faithful, 2003 - 2004 Study Period



100.0% Collected 100.0% Valid
2184 Possible /2184 Collected /2184 Valid
(includes WD and WS)
(VWD-1) (SWS-1)

Figure 4-10. Wind Rose for West Entrance, 2003 - 2004 Study Period

4.4 AIR QUALITY DATA

4.4.1 Pollutant Roses

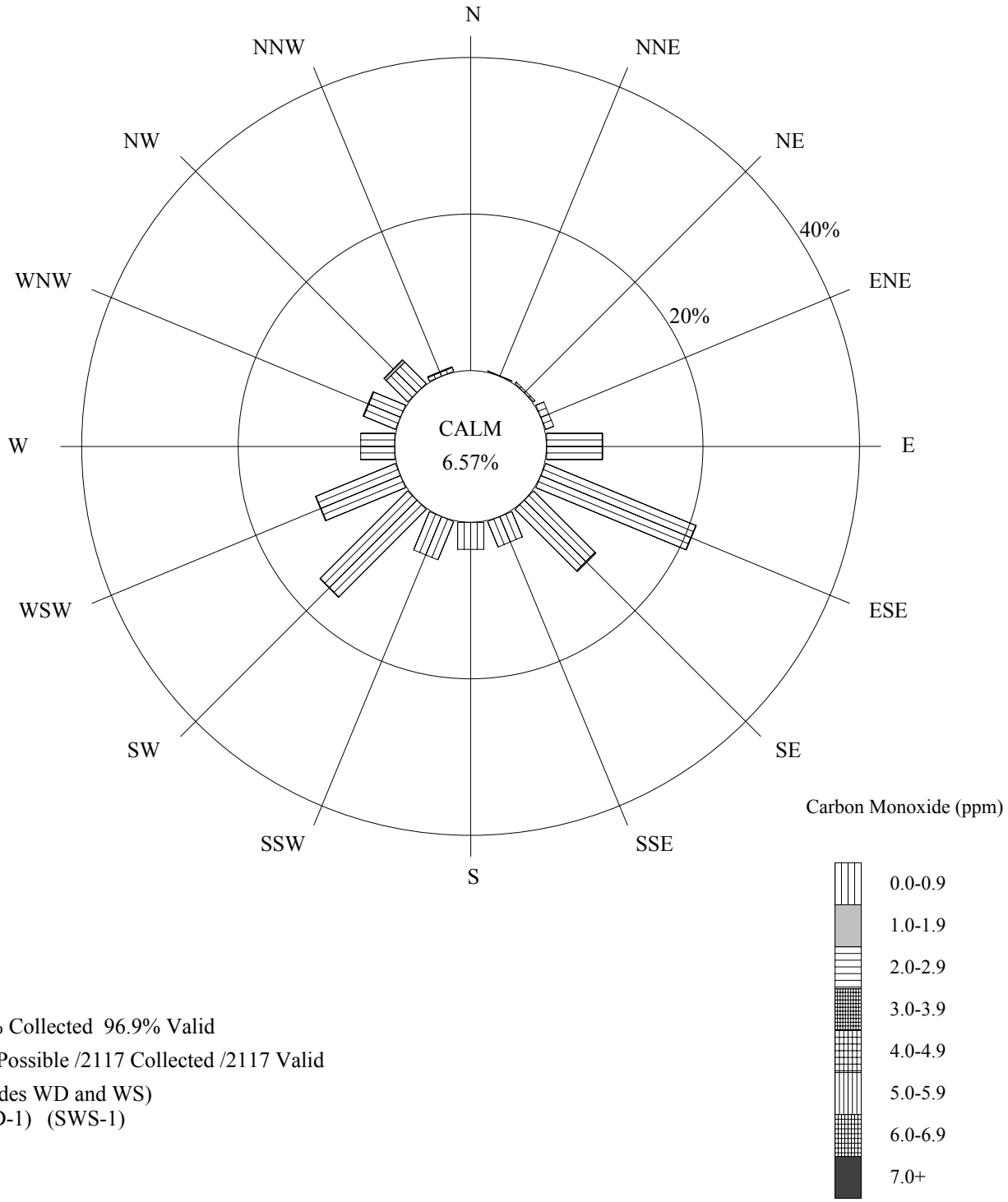
Carbon monoxide (CO) and $PM_{2.5}$ pollutant roses are presented in Figures 4-11 through 4-14. These roses, similar in shape to the wind roses presented in the previous section, graphically describe the wind direction and associated magnitude of each pollutant.

4.4.2 Comparison with National Ambient Air Quality Standards

Tables 4-5 and 4-6 list the five highest 1-hr average daily carbon monoxide maximums for the Old Faithful and West Entrance sites, respectively. Tables 4-7 and 4-8 list the five highest non-overlapping 8-hr running averages for carbon monoxide at both sites. Tables 4-9 and 4-10 list the five highest 24-hr averages for $PM_{2.5}$ for both sites. Valid 24-hr averages must have 75% of the hourly data.

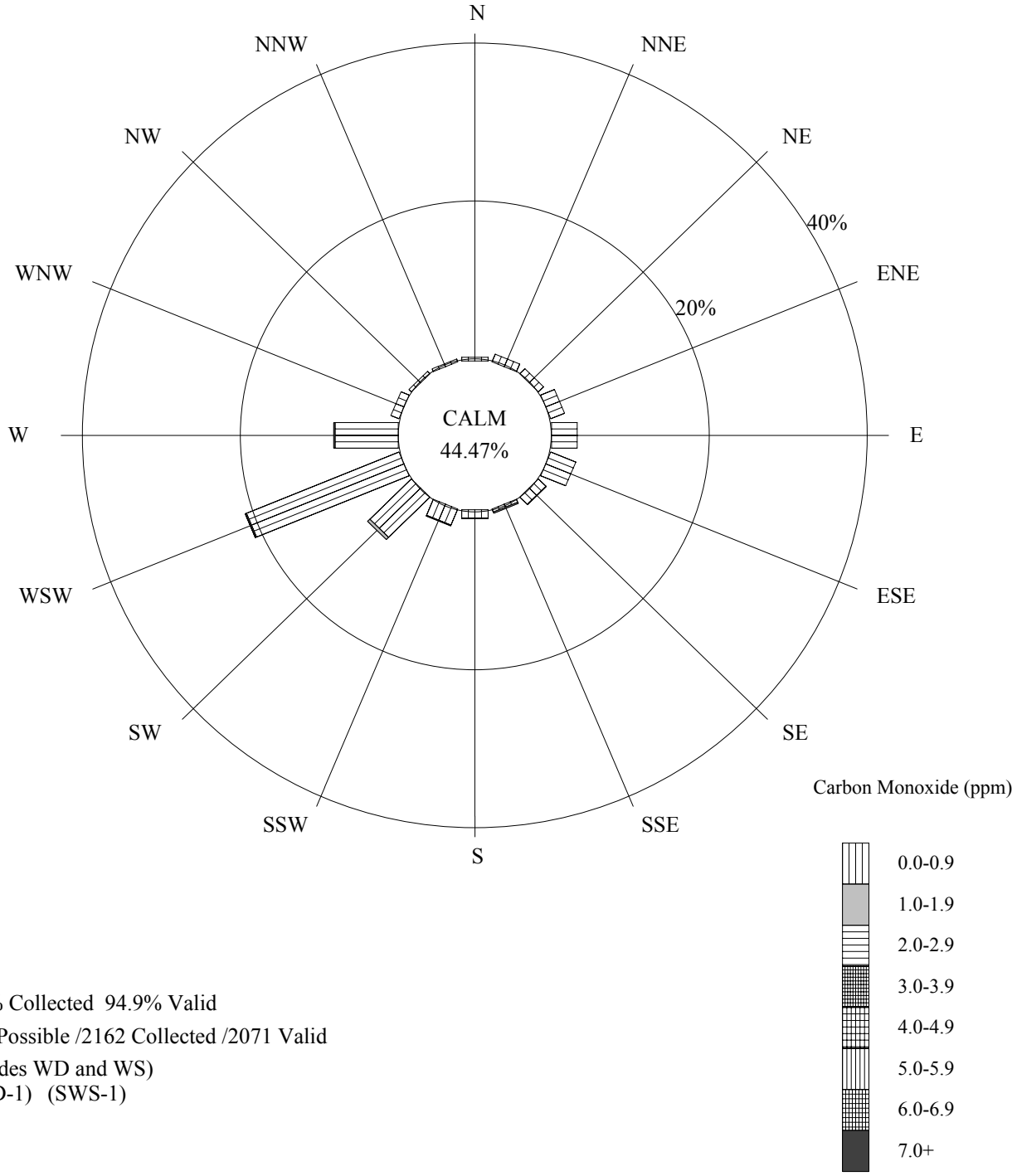
Table 4-11 presents a comparison of the 2003-2004 study CO and $PM_{2.5}$ data to the National Ambient Air Quality Standards (NAAQS). At no time during the study period did CO or $PM_{2.5}$ approach their respective standards. The highest hourly carbon monoxide value was 6% of the 1-hr standard for carbon monoxide at the Old Faithful site, and 18% of the standard at the West Entrance site. The highest 8-hr carbon monoxide running average was 10% of the 8-hr standard for carbon monoxide at the Old Faithful site, and 14% of the standard at the West Entrance site. The highest 24-hr average for $PM_{2.5}$ was 25% of the 24-hr standard for $PM_{2.5}$ at the Old Faithful site, and 26% of the standard at the West Entrance site.

Table 4-12 presents the same comparisons for the 2002-2003 study. The most significant changes in pollutant concentration between years includes a reduction in $PM_{2.5}$ at Old Faithful and a reduction in CO (both the 1-hr and 8-hr averages) at the West Entrance in the 2003-2004 study period.



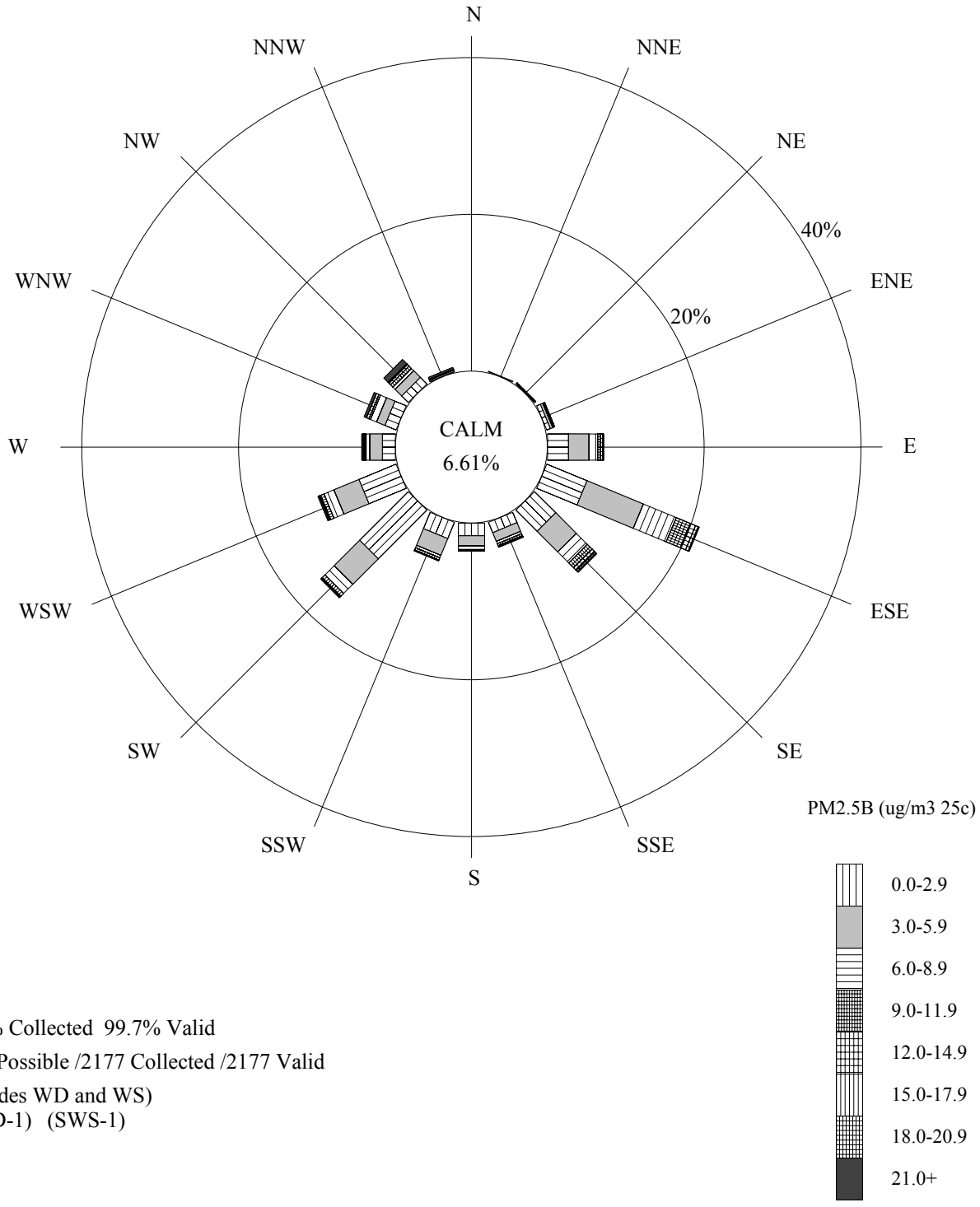
96.9% Collected 96.9% Valid
2184 Possible /2117 Collected /2117 Valid
(includes WD and WS)
(VWD-1) (SWS-1)

Figure 4-11. CO Pollutant Rose for Old Faithful, 2003 - 2004 Study Period



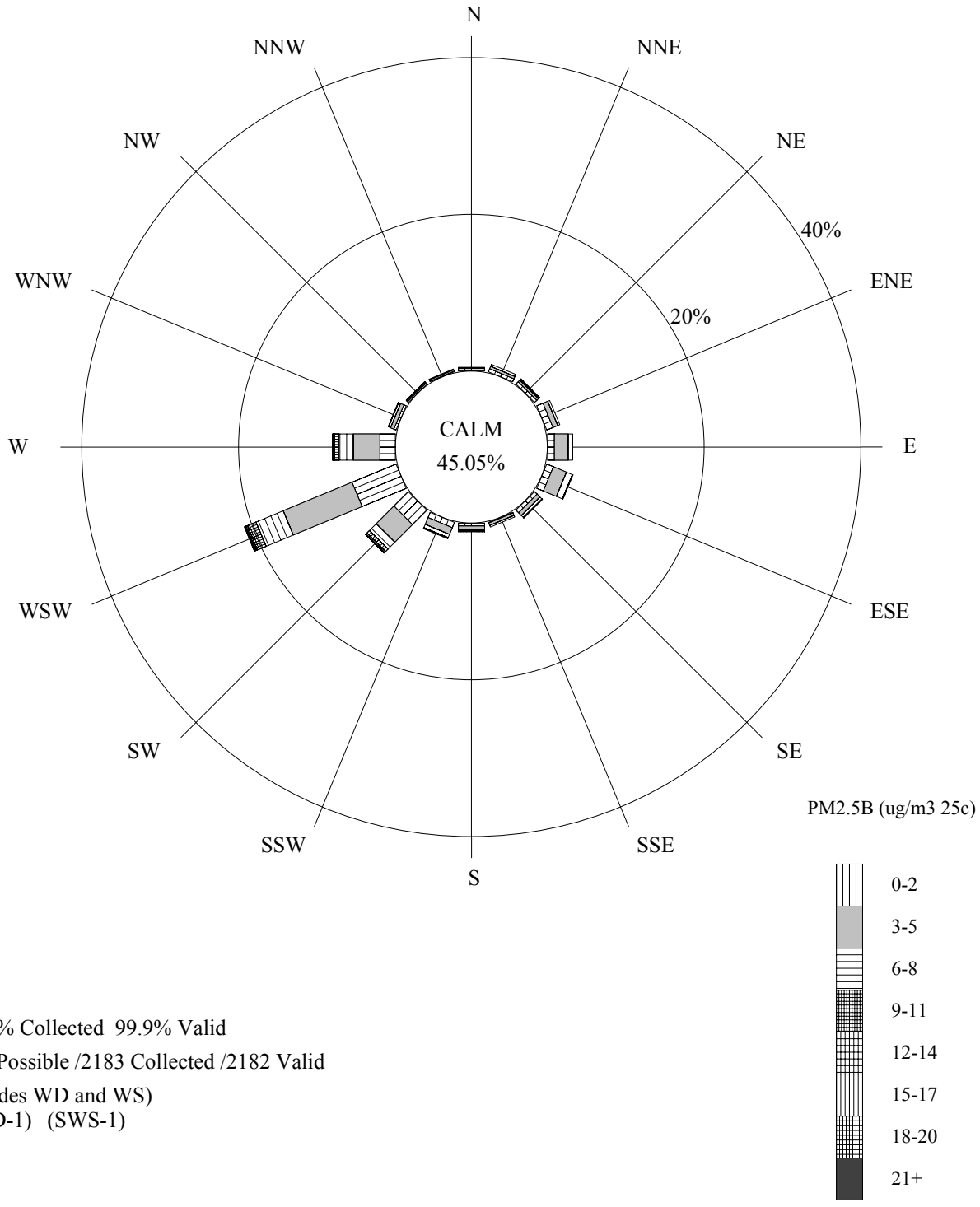
99.0% Collected 94.9% Valid
2183 Possible /2162 Collected /2071 Valid
(includes WD and WS)
(VWD-1) (SWS-1)

Figure 4-12. CO Pollutant Rose for West Entrance, 2003 - 2004 Study Period



99.7% Collected 99.7% Valid
2184 Possible /2177 Collected /2177 Valid
(includes WD and WS)
(VWD-1) (SWS-1)

Figure 4-13. PM2.5 Pollutant Rose for Old Faithful, 2003 - 2004 Study Period



100.0% Collected 99.9% Valid
2184 Possible /2183 Collected /2182 Valid
(includes WD and WS)
(VWD-1) (SWS-1)

Figure 4-14. PM2.5 Pollutant Rose for West Entrance, 2003 - 2004 Study Period

Table 4-5
Carbon Monoxide
Five Highest 1-Hour Average Daily Maximums
Yellowstone National Park – Old Faithful
Winter Use Air Quality Monitoring Study

Rank	Date	Hour	Concentration (ppm)
1	2/28/04	8	2.20
2	12/26/03	11	1.70
3	2/2/04	7	1.70
4	2/14/04	7	1.50
5	1/20/04	12	1.40

Table 4-6
Carbon Monoxide
Five Highest 1-Hour Average Daily Maximums
Yellowstone National Park – West Entrance
Winter Use Air Quality Monitoring Study

Rank	Date	Hour	Concentration (ppm)
1	12/23/03	17	6.40
2	2/12/04	17	3.10
3	12/27/03	9	2.70
4	1/14/04	9	2.30
5	1/3/04	9	2.10

Table 4-7
Carbon Monoxide
Five Highest Non-overlapping 8-Hour Running Averages
Yellowstone National Park – Old Faithful
Winter Use Air Quality Monitoring Study

Rank	Date	Hour Ending	Concentration (ppm)
1	12/29/03	8	0.90
2	2/28/04	14	0.90
3	2/5/04	15	0.80
4	1/20/04	18	0.70
5	1/25/04	13	0.70

Table 4-8
Carbon Monoxide
Five Highest Non-overlapping 8-Hour Running Averages
Yellowstone National Park – West Entrance
Winter Use Air Quality Monitoring Study

Rank	Date	Hour Ending	Concentration (ppm)
1	12/23/03	18	1.30
2	2/12/04	18	0.80
3	1/3/04	10	0.70
4	12/21/03	19	0.60
5	12/27/03	9	0.60

Table 4-9
$PM_{2.5}$ Five Highest *24-Hour Averages
Yellowstone National Park - Old Faithful
Winter Use Air Quality Monitoring Study

Rank	Date	Concentration (ug/m3)
1	1/25/2004	16.42
2	3/13/2004	14.79
3	2/28/2004	13.79
4	12/27/2003	13.08
5	2/5/2004	10.83

*24-Hour Averages must include 75% of the hourly data

Table 4-10
$PM_{2.5}$ Five Highest *24-Hour Averages
Yellowstone National Park -West Entrance
Winter Use Air Quality Monitoring Study

Rank	Date	Concentration (ug/m3)
1	2/4/04	8.00
2	3/8/04	6.75
3	1/22/04	6.71
4	1/23/04	6.58
5	1/27/04	6.54

*24-Hour Averages must include 75% of the hourly data

Table 4-11
Comparison of PM2.5 and CO Study Results to NAAQS
2003-2004 Study Period

Location		Max 1-hr PM2.5 (ug/m3)	Max 24-hr PM2.5 (ug/m3)	Percent of PM2.5 Standard	Max 1-hr CO (ppm)	Percent of CO Standard	Max 8-hr CO (ppm)	Percent of CO Standard
Yellowstone NP	Old Faithful	151	16	25%	2.2	6%	0.9	10%
	West Entrance	29	17	26%	6.4	18%	1.3	14%
NAAQS	Standard		PM2.5		CO		CO	
	1-hour	- -	- -		35		- -	
	8-hour	- -	- -		- -		9	
	24-hour	- -	65		- -		- -	

* West Entrance data provided by the State of Montana

Table 4-12
Comparison of PM2.5 and CO Study Results to NAAQS
2002-2003 Study Period

Location		Max 1-hr PM2.5 (ug/m3)	Max 24-hr PM2.5 (ug/m3)	Percent of PM2.5 Standard	Max 1-hr CO (ppm)	Percent of CO Standard	Max 8-hr CO (ppm)	Percent of CO Standard
Yellowstone NP	Old Faithful	200	37	57%	2.9	8%	1.2	13%
	West Entrance*	81	15	23%	8.6	25%	3.3	37%
NAAQS	Standard		PM2.5		CO		CO	
	1-hour	- -	- -		35		- -	
	8-hour	- -	- -		- -		9	
	24-hour	- -	65		- -		- -	

* West Entrance data provided by the State of Montana

4.4.3 Nephelometer Data

The nephelometer consists of a sampling chamber and a light source confined to a small volume so that the instrument may directly measure the light scattered by aerosols and gases at a fixed point. Nephelometers provide continuous, five-minute measurements of particle scattering (b_{sp}). The atmospheric scattering coefficient, b_{scat}, can be directly estimated from this measurement by adding Rayleigh scattering (b_{ray}). An estimated Rayleigh scattering of 10 Mm^{-1}, was used at the Old Faithful site. A more detailed description of the nephelometer system and data reduction and validation procedures used can be found in Section 3.0

Measurements of nephelometer b_{scat} can be combined with measurements of aerosol absorption (b_{abs}) to calculate the total light extinction (b_{ext}). Visual range (in kilometers) can then be calculated using the following equation:

$$\text{Visual Range} = 3912/b_{ext}$$

Aerosol absorption was not measured at the Old Faithful site, but visual range can be approximated by substituting b_{scat} with b_{ext} in the above equation. This will result in an overestimation of visual range. Nephelometer visibility metric data for the monitoring period is represented in Table 4-13 as particle scattering (b_{sp}) and an upper limit on visual range.

Table 4-13
Summary of Visibility Data
Collected by the Nephelometer

Visibility Metric	b_{sp} (Mm^{-1})	Visual Range (km)
Mean of Cleanest 20%	1.8	<332
Mean of All Data	32.2	<93
Mean of Dirtiest 20%	128.8	<28

4.5 TIME-LAPSE VIDEO AND DIGITAL PHOTOGRAPHS

Video and still images collected during the study were most useful for supporting nephelometer data validation, as described in Section 3. No further analyses were performed on these data.

4.6 VEHICLE COUNT DATA

Vehicle counts were recorded by park rangers at the South, West and East entrances to Yellowstone National Park on an hourly basis from 7AM to 4PM from December 17, 2003 through March 14, 2004. Vehicle counts were divided into two categories (1) snow coaches and (2) snowmobiles. On days when the entrances were understaffed, the vehicle counts may be inaccurate or unavailable. On average, 246 snowmobiles and 18 snow coaches entered the park on a daily basis. Table 4-14 lists ten dates with the highest vehicle counts.

Figure 4-19 graphically depicts the vehicle counts recorded at the West, South and East entrances for the 2003-2004 winter study. On average, 57% of the vehicles counted entered through the West entrance, 42% entered through the South entrance, and 1% entered through the East entrance. Figure 4-20 graphically depicts the vehicle counts recorded at the West, South and East entrances for the 2002-2003 winter study. Figure 4-21 presents a comparison between the 2002-2003 vehicle counts and the 2003-2004 vehicle counts for all entrances combined.

Table 4-14
Ten Highest Vehicle Counts
Yellowstone National Park
Winter Use Air Quality Monitoring Study

Rank	Date	Snow Mobiles	Snow Coaches	Total
1	2/21/2004	438	37	475
2	2/28/2004	438	28	466
3	2/15/2004	403	34	437
4	2/14/2004	394	42	436
5	12/29/2003	386	36	422
6	2/20/2004	393	28	421
7	12/27/2003	384	35	419
8	2/17/2004	376	36	412
9	12/13/2003	374	31	405
10	3/14/2004	370	25	395

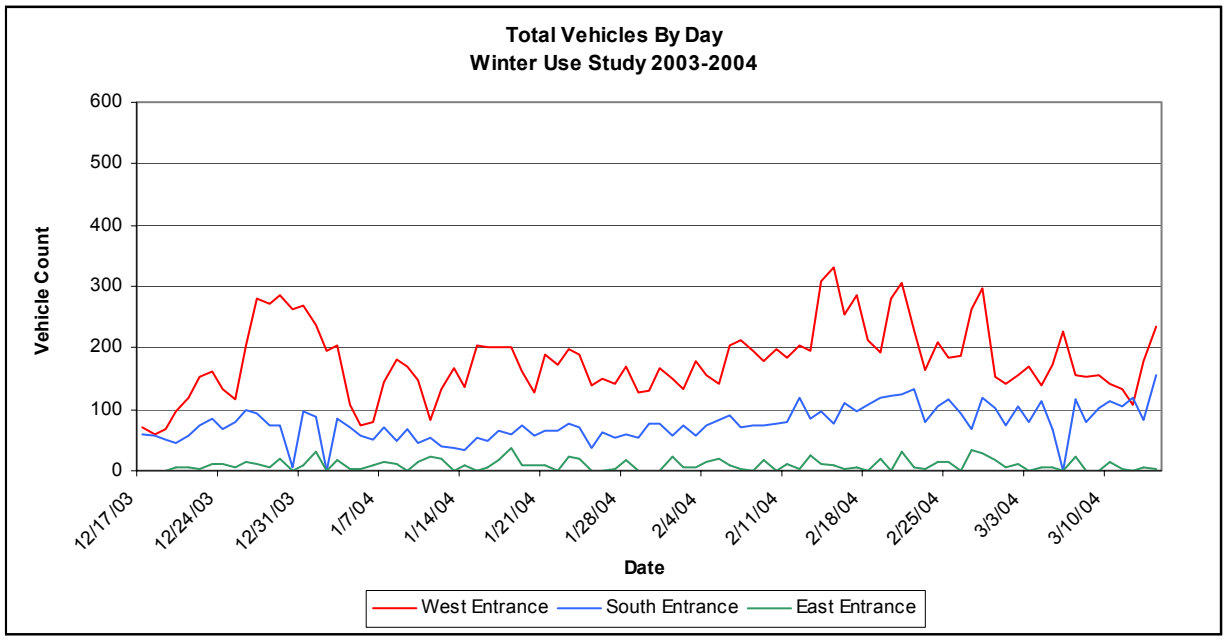


Figure 4-19. Vehicle Counts from the West, South, and East Entrances-2003-2004.

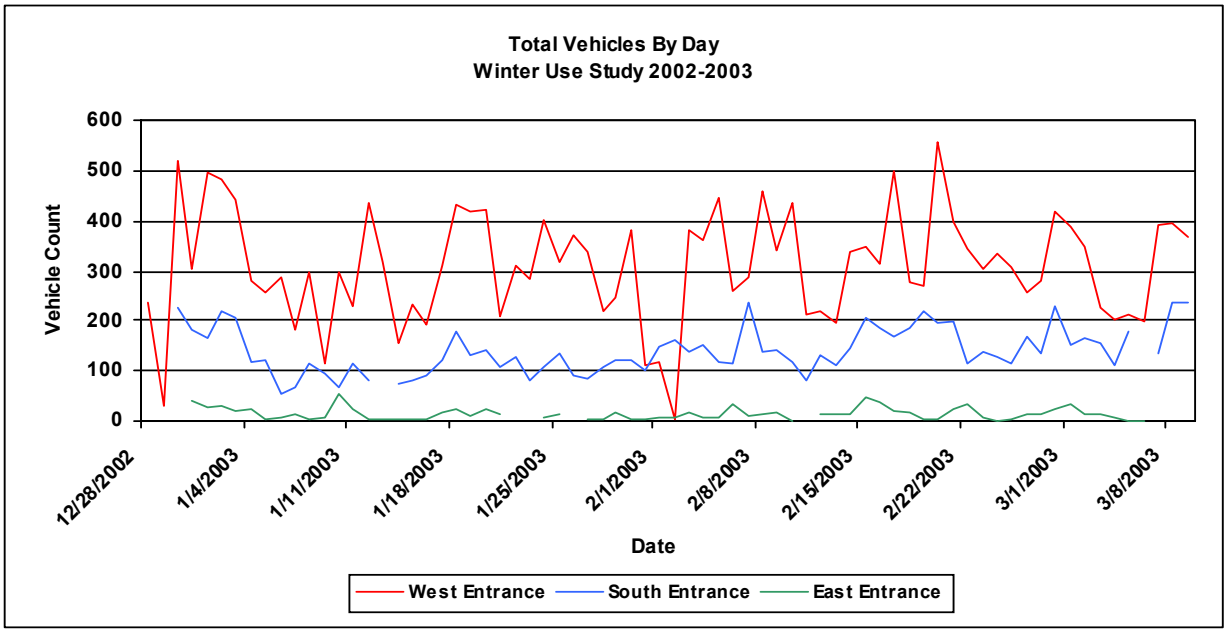


Figure 4-20. Vehicle Counts from the West, South and East Entrances-2002-2003.

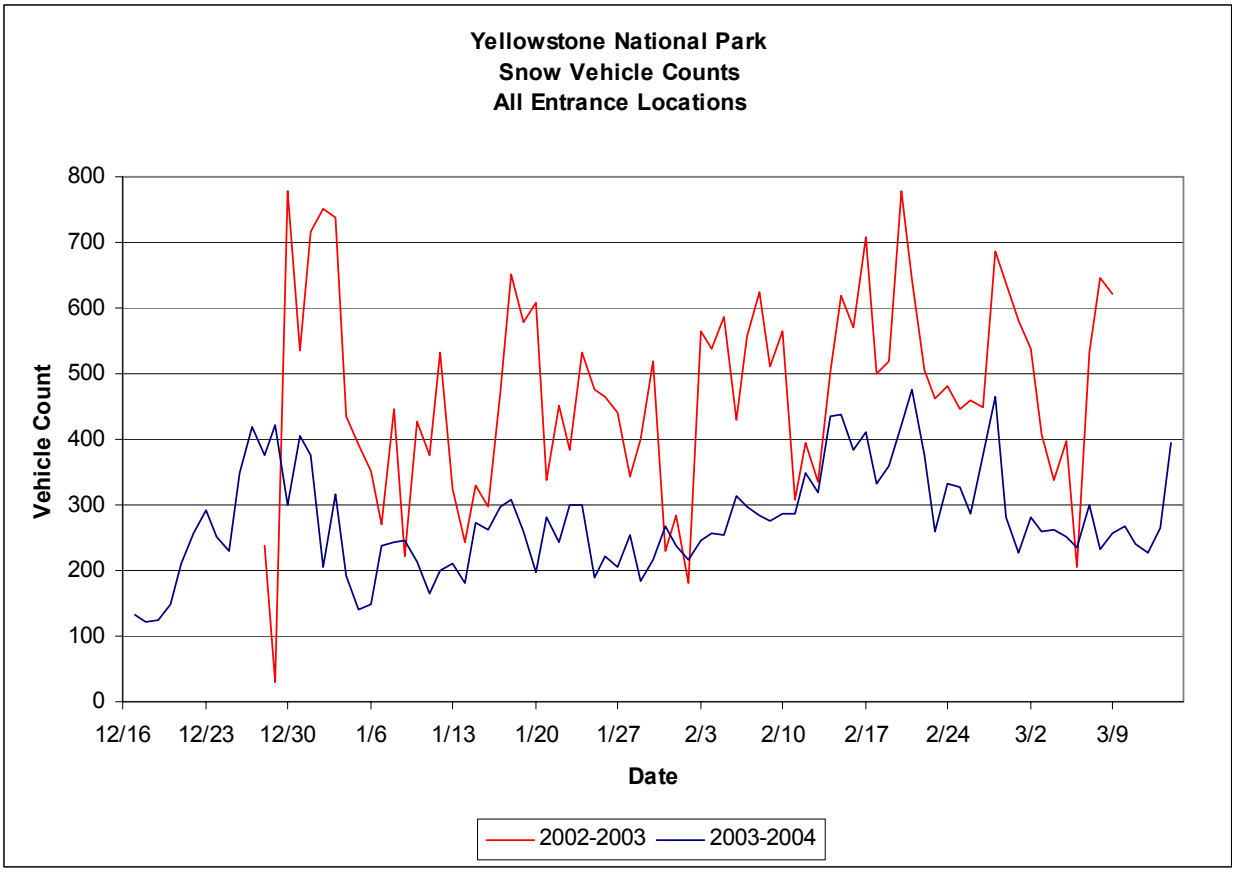


Figure 4-21. Yellowstone National Park, Snow Vehicle Counts, All Entrance Locations, 2002-2003 and 2003-2004 Study Periods.

4.7 DIURNAL PATTERNS OF AIR QUALITY PARAMETERS

Diurnal plots were obtained for each air quality parameter by averaging all of the validated data for each hour of the day. Figures 4-22 and 4-23 present diurnal patterns of CO and $PM_{2.5}$ for the Old Faithful site for both the 2003-2004 and the 2002-2003 study periods. Figures 4-24 and 4-25 present diurnal patterns of CO and $PM_{2.5}$ for the West Entrance site for both the 2003-2004 and the 2002-2003 study periods. $PM_{2.5}$ and CO levels were highest during the daylight hours during the monitoring periods of both studies. $PM_{2.5}$ levels were generally lower throughout the day during the 2003-2004 study than during the previous year. Average CO concentrations at the West Entrance are shown to have been significantly lower during the 2003-2004 study period than during the previous year.

Figures 4-26 and 4-27 present the diurnal pattern of particle scattering (bsp) seen at Old Faithful during both the 2003-2004 and 2002-2003 study periods. Highest particle scattering values during both years occur between 0700 and 1100.

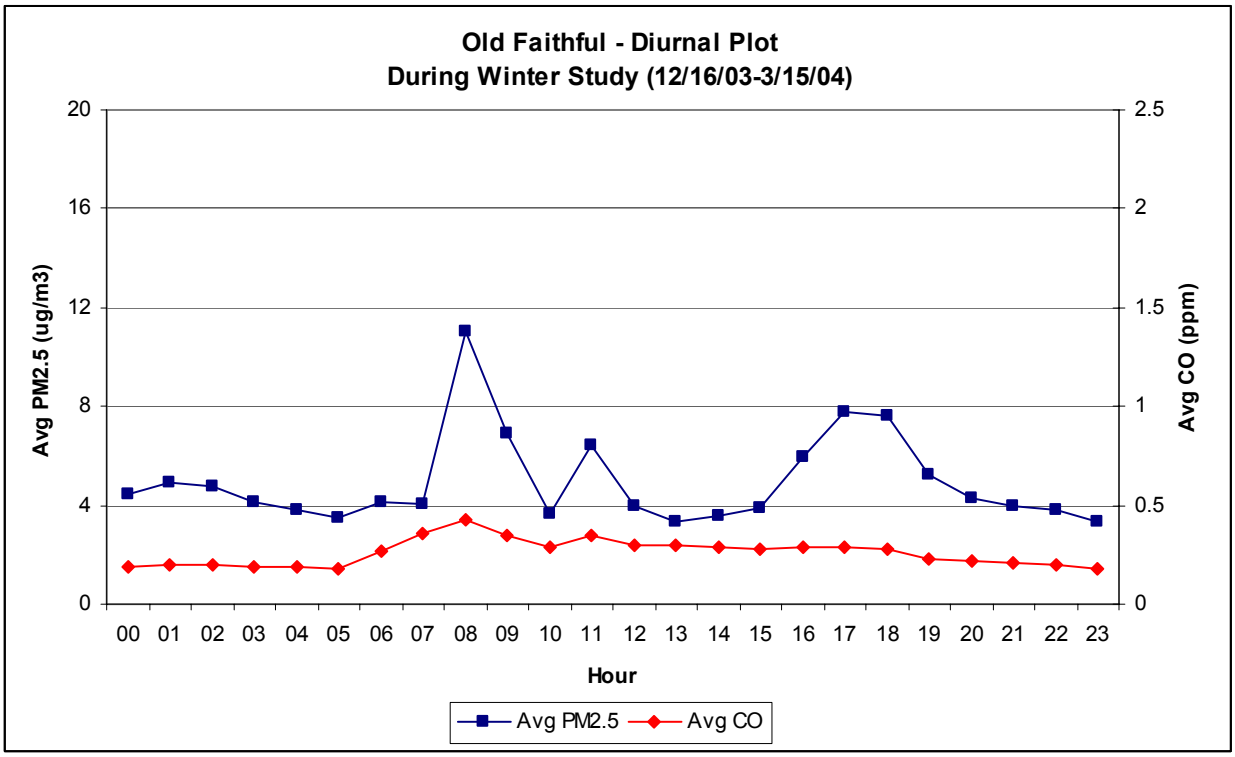


Figure 4-22. Old Faithful, CO and PM2.5 Diurnal Plots, 2003-2004 Study Period.

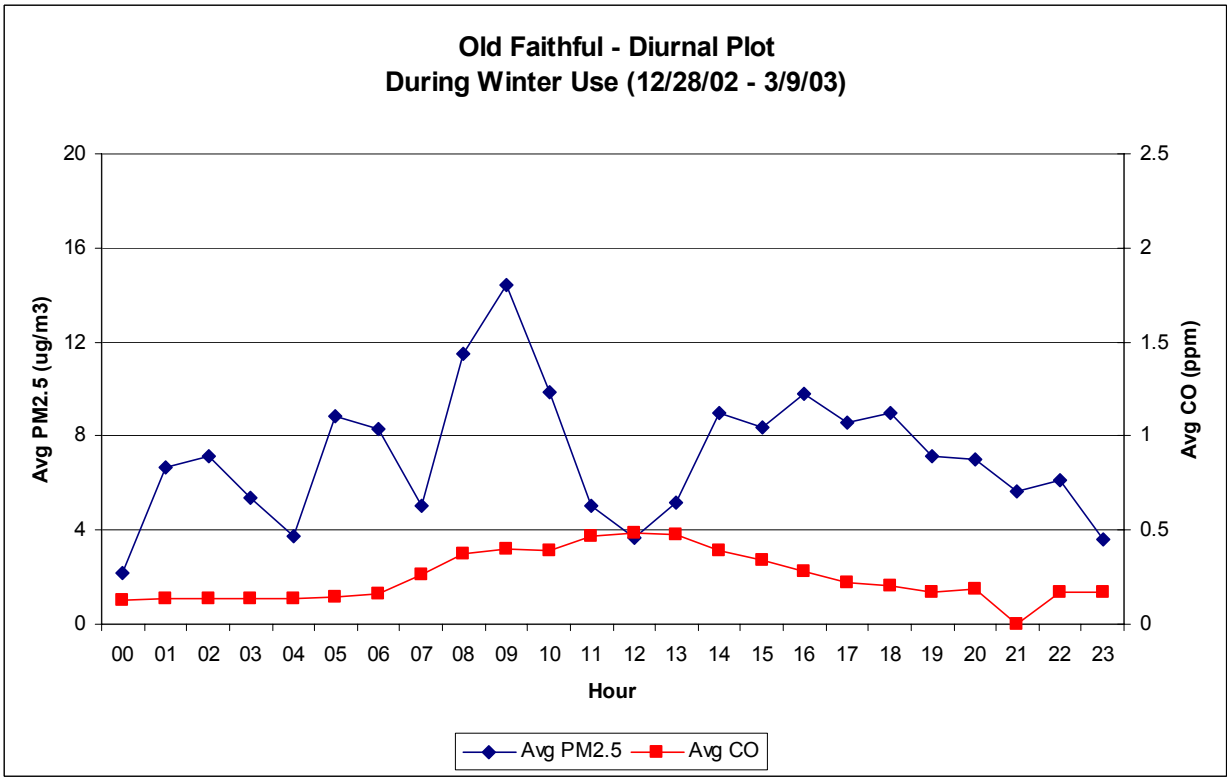


Figure 4-23. Old Faithful, CO and PM2.5 Diurnal Plots, 2002-2003 Study Period.

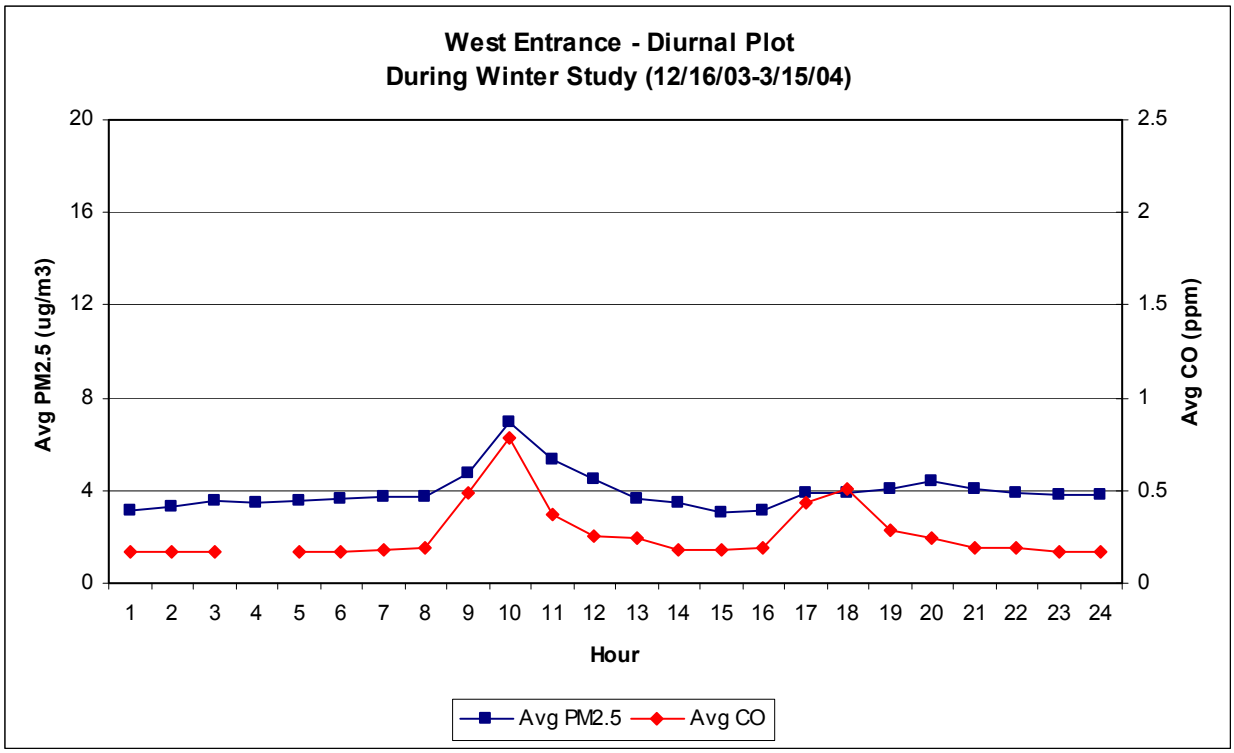


Figure 4-24. West Entrance, CO and PM2.5 Diurnal Plots, 2003-2004 Study Period.

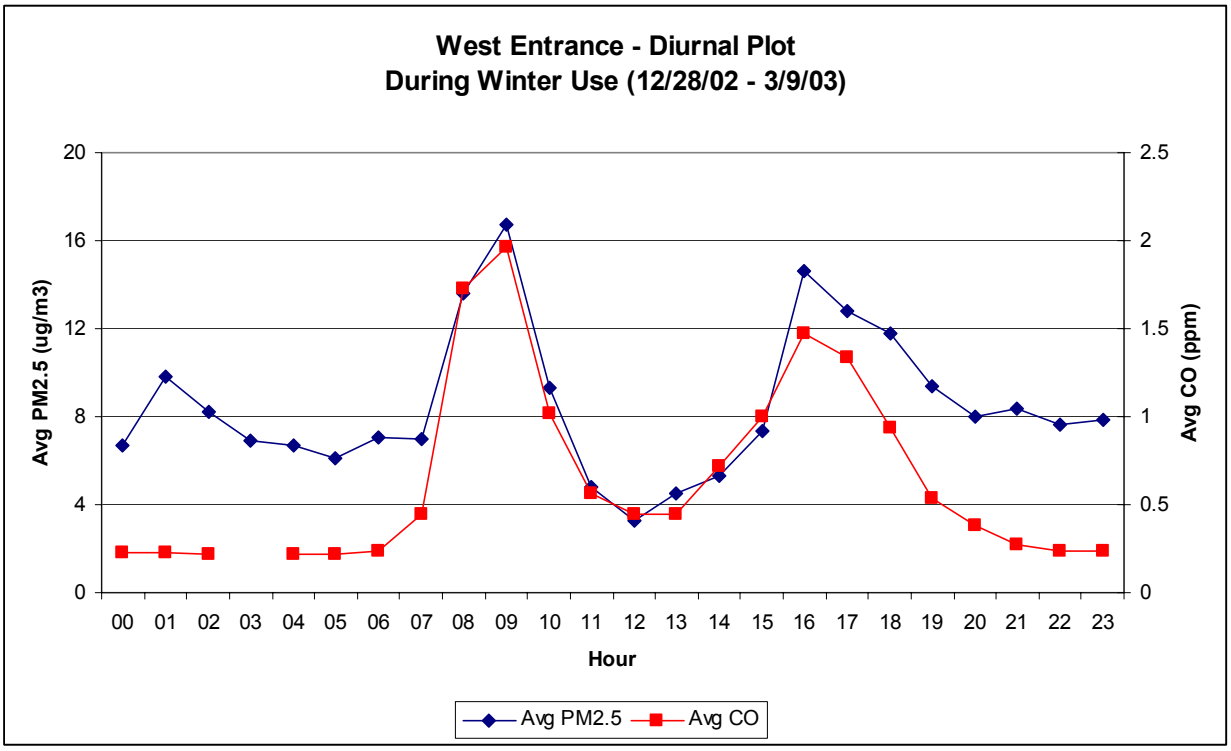


Figure 4-25. West Entrance, CO and PM2.5 Diurnal Plots, 2002-2003 Study Period.

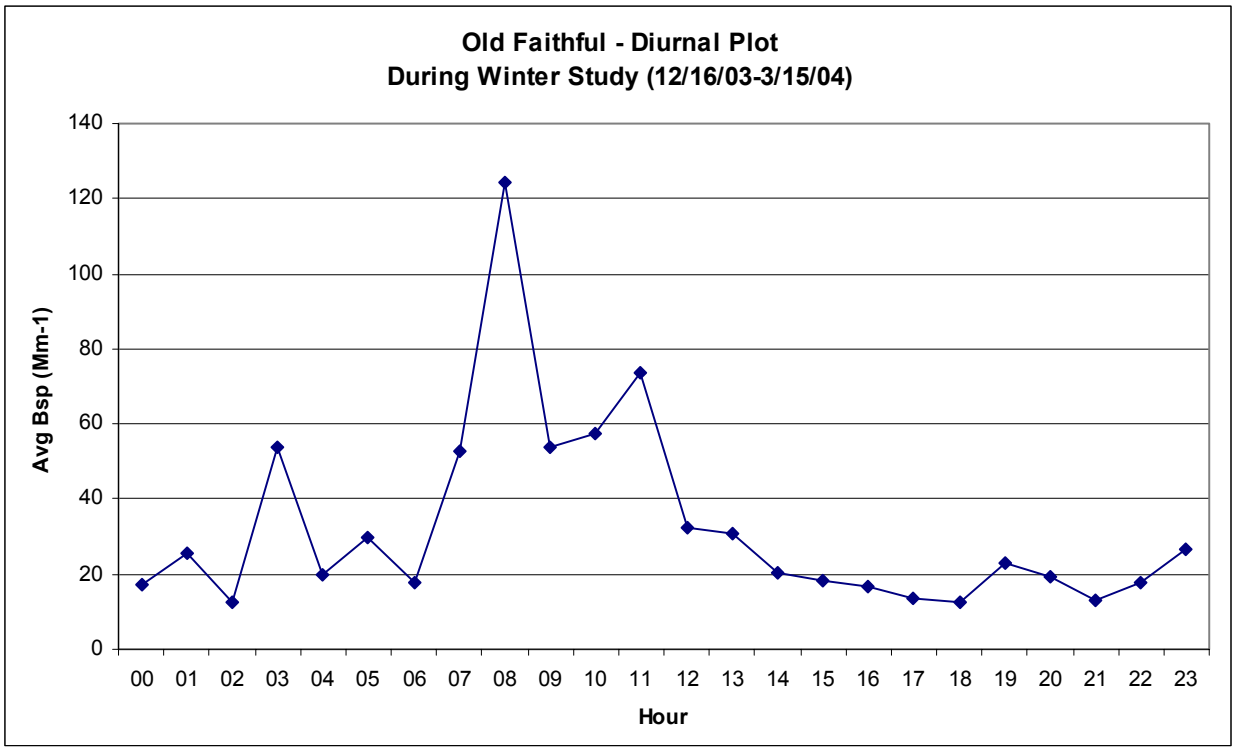


Figure 4-26. Old Faithful, Particle Scattering Diurnal Plot, 2003-2004 Study Period.

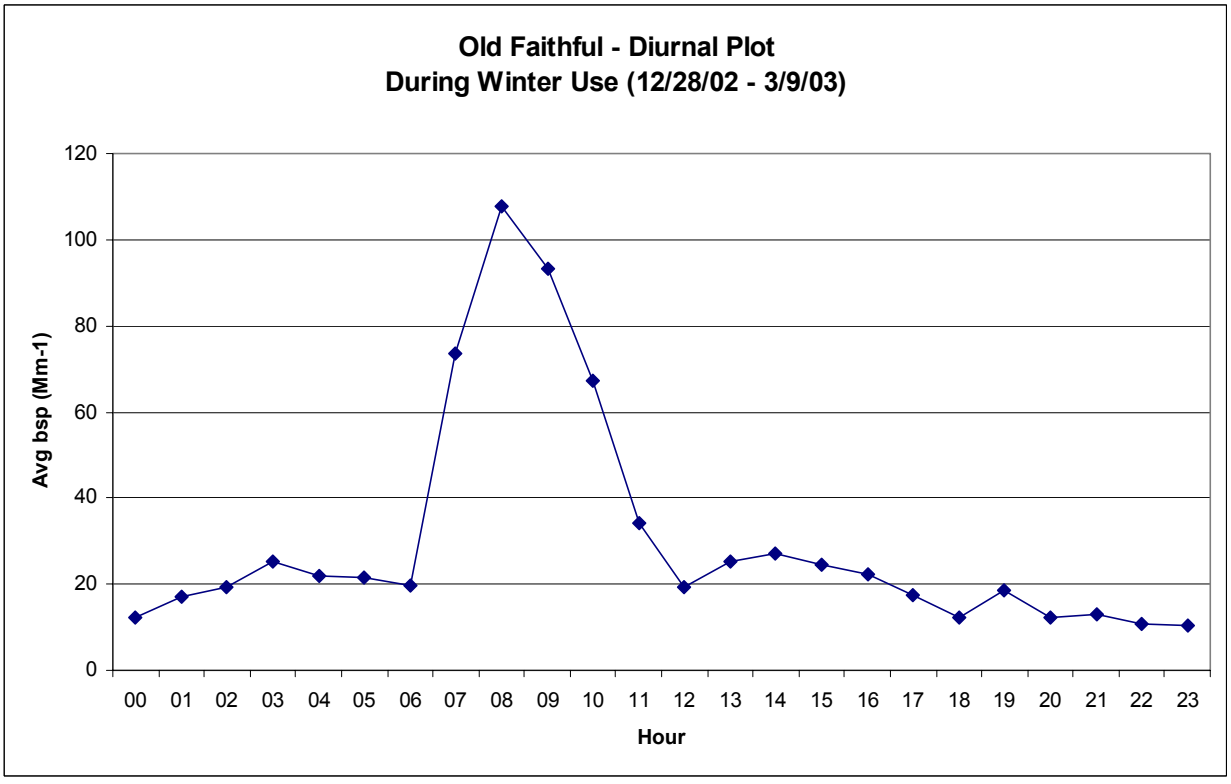


Figure 4-27. Old Faithful, Particle Scattering Diurnal Plot, 2002-2003 Study Period.

4.8 RELATIONSHIPS BETWEEN AIR QUALITY PARAMETERS

Analysis of the 2003 – 2004 air quality data did not show any strong correlations between hourly CO, $PM_{2.5}$, and light scattering. (Analysis of the 2002 – 2003 data also yielded poor correlations between parameter pairs.) Scatter plots summarizing the relationship between air quality parameters for 2003 – 2004 are presented in Figures 4-28 through 4-30. These plots represent data collected between 7AM and 7PM (roughly during daylight and peak vehicle activity hours), for 12/16/2003 through 3/15/2004.

There is poor correlation between CO and $PM_{2.5}$ at Old Faithful (R^2 = 0.23) and essentially no correlation at the West Entrance (R^2=0.08).

$PM_{2.5}$ and b_{sp} at the Old Faithful site show a better, but still weak correlation (R^2 = 0.43). These parameters are usually expected to show better correlation, but may not have during this study for the following reasons:

- The instruments operated under different RH conditions
- Differences in instrument measurements
- Frequent, short-lived fog events are believed to have affected the nephelometer

Different components of $PM_{2.5}$ have different light scattering efficiencies and the nephelometer and BAM operated under different RH conditions. The nephelometer operated under ambient RH conditions, outside of the shelter while the BAM was operated inside of the heated shelter, which most likely led to drier conditions.

One of the differences between the two measurements is that the $PM_{2.5}$ measurement includes elemental carbon, which will pas through the nephelometer undetected. Elemental carbon particles are smaller than most other particles and tend to absorb rather than scatter light. These particles are emitted directly into the air from virtually all combustion activities, but are especially prevalent in diesel exhaust and smoke from wood burning.

Nephelometer measurements can be greatly influenced by meteorology. During periods of fog, heavy rain, high relative humidity (>90%), blowing snow, and other extreme meteorological conditions, nephelometer reading will no longer correspond to optical properties of particulates in the atmosphere. ARS filtered the data for weather or other interferences using a maximum hourly threshold (bsp <5,000 M_M^{-1}), a maximum allowable RH (>90%), and time-lapse video and digital photographs (to screen for fog events).

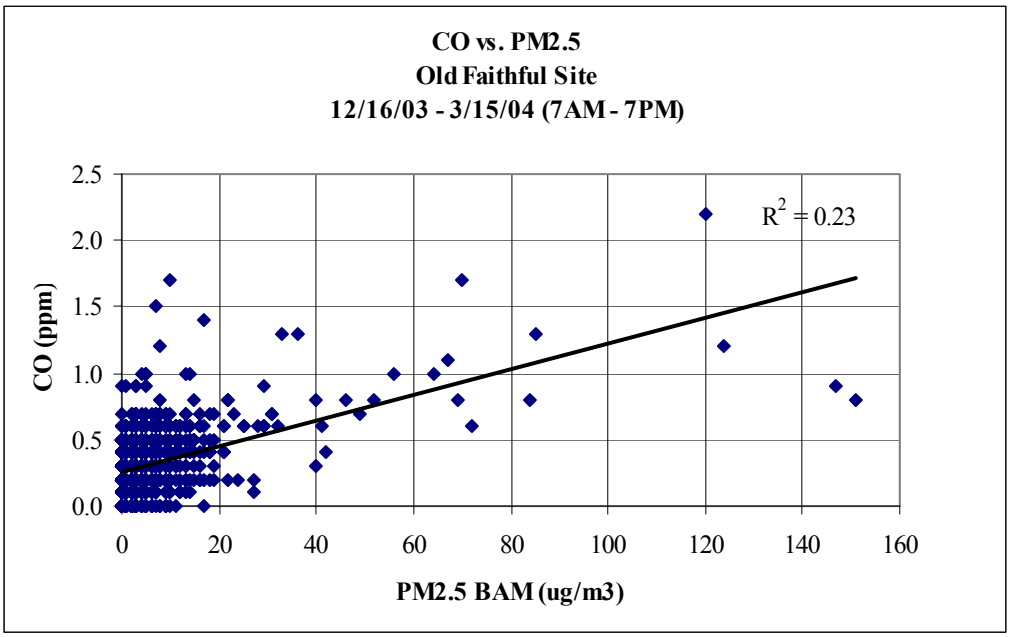


Figure 4-28. Old Faithful, CO vs. PM2.5, 2003 – 2004 Study Period.

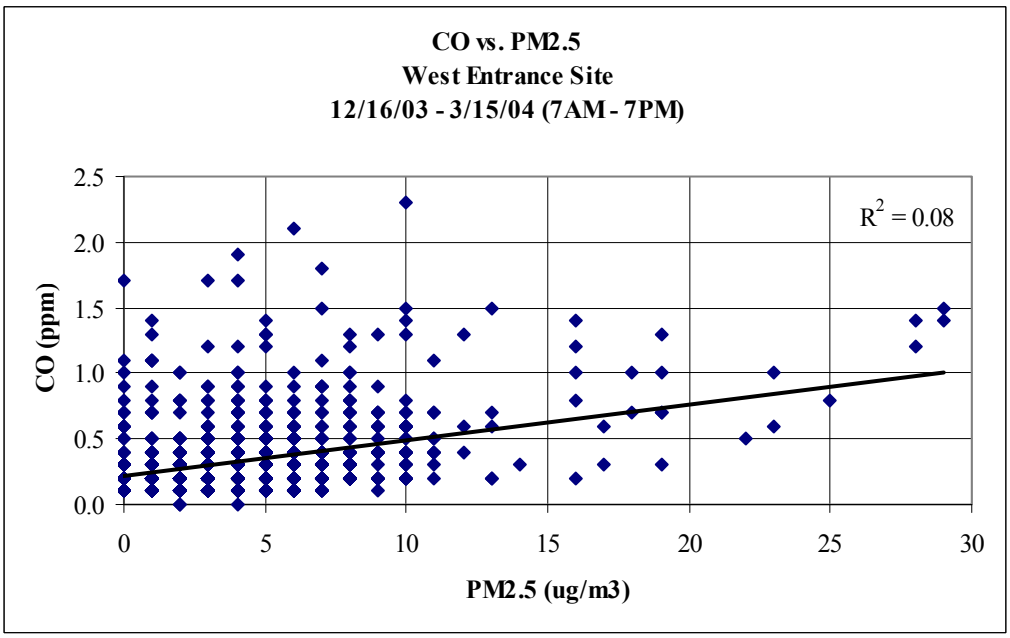


Figure 4-29. West Entrance, CO vs. PM2.5, 2003 – 2004 Study Period.

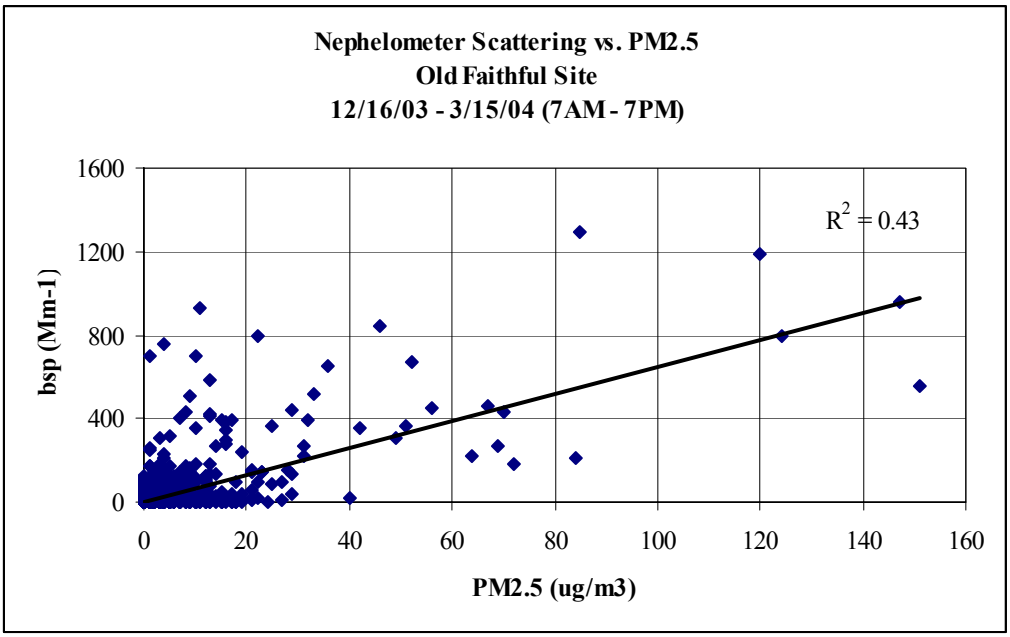


Figure 4-30. Old Faithful, Particle Scattering vs. PM2.5, 2003 – 2004 Study Period.